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APPETITE LEVELS OF FOOD CONSUMPTION: A TECHNIQUE FOR MEASURING FOODS IN TERMS OF PSYCHOLOGICAL AND NUTRITIONAL VALUES COMBINED*

BY W. FRANKLIN DOVE
University of Maine, Orono

THE production of foods for human consumption, in view of the recent regulations for civilian rationing, for Lend-Lease, and for military purposes, enters a new stage of government control. This control, new in itself, must make the biologist inquire whether some form of *biological* engineering of food production, expressing biological or consumer value, is not long overdue.

* These first surveys on appetite levels could not have been secured without the generous cooperation of a large group of Orono townspeople, expressing sufficient interest in the problems of foods and nutrition to prompt them to fill out the survey blanks in the detailed and complete form required for this analysis. Many subjects were secured through instructors in Red Cross and Civilian Defense nutrition classes and through the town of Orono nursery school. Many subjects were members of the University of Maine faculty.

For this assistance in securing subjects the writer is greatly indebted to Mildred Covell; for the Holorith card-sorting and the large number of statistical constants required for the final analysis and interpretation, he is also indebted to other technical assistants on the staff of the Biological Laboratory, Maine Agricultural Experiment Station, including Marguerite Cotter, Belle Dall, and Emmeline Kenney.

According to the commonly accepted point of view, the consumer has already been recognized in food production programs, but this is true only in so far as the consumer has been made aware, on the one hand, of the nutritional values of foods in terms of his daily needs for protein, calories, vitamins, and minerals, and exposed, on the other hand, to efforts to change his preferences for the different foods that happen to be available for consumption. In other words, foods have been evaluated by the *quantity* of nutrients they possess per unit weight, primarily a producer's measure, or, far more loosely, by indications of consumer preference; but the *association* of the nutrient values of the food consumed with the reaction of the consumer in terms of the degree of preference—a combination which forms the essence of consumer value of food—has been to date very largely neglected.

Recently each of the bicornal aspects of the problem has received increased but separate emphasis, first from the rapid development of physico-chemical and photometric methods of evaluating nutrients in the foods and of determining nutritional status in the subjects, and second from the extension of the psychological phases by the search for appropriate techniques (Bavelas, 1942 and Lewin, 1942). These psychological techniques, however, have not utilized our knowledge of the biochemical characteristics of foods nor the nutritional status of subjects, and their applicability is consequently limited to the field of education—the chief purpose, of course, for which they were devised.

Of more relevance to the necessary fusion are the experiments of Richter (summarized in 1942) designed to measure the demands of the body as expressed in terms of appetite for different purified nutrients and minerals in solution. As an experimental technique in physiological psychology, this approach to the problem has secured its chief outlet to date by indicating the chemical nature of self-regulating functions, especially the interrelation between the organs of taste and the glands of internal secretion.

Another approach to the problem has been made by the author as an attempt to fuse these two divergent aspects of food-getting by a combination of an analysis of degrees of preference with the biochemical values of natural foods at accepted rates of consumption (Dove, 1935 to 1943b). Natural foods have been used in these experiments because natural foods, up to the near present, have formed the nutrient milieu upon which have depended survival and evolution. The author's

approach to the problem of food-getting secures its particular outlet in revealing and in indicating the means of resolving problem foods, subjects, or conditions.

In order to extend this method by securing an objective technique adaptable to the human subject whereby both nutritional and psychological measures of value may be fused, the following technique has been devised to measure the combined end result or, as we have termed it here, the *appetite levels* of food consumption.

APPETITE LEVELS OF CONSUMPTION

The potential importance of appetite levels has been over-looked because of both the simplicity and the complexity of the concept: Simplicity in the fact that appetite, likes, and dislikes enter into the language of every household, and complexity in the fact that the individual appetite is not an infallible guide to good nutrition (Dove, 1934, p. 540), that it is whimsical, vacillating, subject to prejudice and imitation, and may be altered by conditioning or learning. Appetite levels also vary secondarily with racial type, region, and economic status. For these reasons the biochemist and the nutritionist have had but little confidence in the psychological approach to food-getting. Nevertheless these subsidiary causes of differences could be treated if only an appropriate technique for measuring appetite levels were available; such a technique could then tap the reservoir of common household appetite knowledge. The present survey on appetite levels has this purpose in mind.

Our recognition of the importance of appetite levels of consumption is based upon the results of numerous experiments carried on by the writer during the past ten years on the patterns for natural foods shown by a number of different species of animals including man. These experiments have shown (first) that each kind of food is preferred by each species within a range of acceptance so characteristic of both food and consumer that species patterns can be constructed to demonstrate the consistencies (Dove, 1935, p. 483). These preferences have also been found (second) to have a biological consistency and a statistical significance in terms of preference even for different varieties of the same food (Dove, 1943a and 1943b). Furthermore (third) preferences for different foods have been shown to be so consistent for each food that removal of any one food A from a pattern-mixture A to G will

be followed, when both A and B to G are presented for free selection, by the selection of A and B to G at the same levels at which they were originally preferred when A, B, C, D, E, F, G were presented for separate selection.[1] And finally (fourth) when the nutritional value of one food of the pattern is depleted by genetic or other changes (depleted in vitamin A, for instance) the rate of consumption will still be maintained even at the risk of a lower survival rate and even though survival, on theoretical assumptions, might be sustained by a shift in pattern from the one food now depleted to another food now left relatively higher in the missing nutrient (Dove, 1939). The further extension of this technique to the human subject therefore promises to be important.

This study on appetite levels of food consumption, then, represents the results of a preliminary attempt to apply to the human being this concept of appetite levels already established for experimental animals in previous reports under the name of *food patterns,* formed as a composite of appetite levels of several to many different foods, and also under the name of *palatability differences,* when comparisons were made between varieties of the same food. Regardless of name, whether put into terms of *palatability differences* between varieties of the same food, or as *appetite levels* for each food, or as *food patterns* for a group of different foods, nutritional behavior is the phenomenon under observation, and yet, at the same time, each method of approach tests different aspects of the behavior. The word *appetite* may not include all of the elements, especially of gross hunger and of hidden hunger, which come to expression in food patterns or in palatability differences; nevertheless the term *appetite levels* makes possible a clearer recording of differences between foods by the use of a word recognized by everyone.

As was stated previously, foods may be evaluated in terms of the quantity of nutrients in a given quantity of food, but this quantity of nutrients has little consumer 'meaning' and may even be misleading and erroneous if the consumer qualities of degrees of preference and rates of consumption (appetite levels) are omitted. This may be explained by comparing first, several foods from the point of view of *nutrients*

[1] This fact was utilized in constructing basal rations for the analysis of comparative nutritional value of proteins (Dove, 1943, p. 230) and in the construction of the "substitution technique" required for the comparison of palatability differences in varieties of legumes, cabbages, and kale (Dove, 1943b).

per unit quantity and second, the same foods on the basis of quantity, quality, and preference as derived from a preliminary survey of appetite levels.

A SURVEY OF APPETITE LEVELS

The survey was carried out as a questionnaire among three groups of adults, two of women and one of men. All three groups were selected as nearly as possible to represent moderate physical activity.

The chief characteristic of the survey, and its chief difference from previous food habit surveys, rested in the request from each subject for a classification of each of 228 foods according to two bases: First, according to preference or taste, as follows: Never tried the food (N), allergic to the food (Al), disliked the food (D), tolerated the food only when hungry (T), desired the food moderately well (M), considered the food good (G), or considered the food very good (VG); Second, according to the rate at which the food was desired in terms of servings per week, regardless of any nutritional value in the foods and assuming the supply to be unlimited and available the year round, summer and winter, with the provision that the subject could afford to purchase the food at any time. One year was included in the estimation in order to include seasonal foods. The list of foods used was selected so as to represent a national distribution of foods of known chemical and nutritional value.

Since the subjects were secured in a University town, they represented a larger section of the country than the one state Maine. Only 64 per cent of the 129 individuals in all three groups had been born and reared in Maine. The 36 per cent born and reared outside the state came from twenty-four different states. Consequently the foods grown in other parts of the country and not easily available in Maine were recognized by a certain proportion of the subjects; since the records were treated individually, the 36 per cent who might have been acquainted with the food elsewhere tended to rate the food in terms of degree of preference as they had once known it, while the 64 per cent not acquainted with the food tended to record it as N (never tried). Seventy-five per cent of the subjects had been residents of the local community for five or more years. The racial stock was predominantly from the British Isles and Northern Europe in the following frequency of mention: English, Scotch, Irish, French, German, Dutch. All of the middle class,

the subjects represented the average present-day consumer, not the producer of food who might also consume some of what he produces, nor the mass-fed factory worker, but the consumer who must secure most of his food through cash purchase.

While a more extensive report on all 228 foods and on all 129 subjects in the three exploratory surveys will appear elsewhere, brief excerpts from the data will demonstrate here some of the important features of the method.

As a demonstration of the statement that appetite levels of consumption must be known before real consumer values of foods may be ascertained, data on 7 of the 63 vegetables in the survey are presented in Table 1.

These seven vegetable foods have been selected for demonstration purposes chiefly because they represent foods eaten separately and not mixed or subdivided too frequently. The appetite levels should thereby indicate distinctly the preference differences for the different kinds of food. Demonstration foods of this kind could have been selected, however, from any one of the six other classes of foods, i. e. of fruits; cereals; nuts; meats, fish, and poultry; dairy produce; and miscellaneous foods.

In Table 1 appetite levels of several consumer subgroups, X^b, X^c, X^a, and X^{max}, as described in the table footnotes, are presented for all three survey groups, together with records on experience with each food and the relative nutritional value.

From this table one may gain a general impression of the statistical regularity of appetite levels, heretofore under suspicion, as secured in repeated surveys on the same foods within the same class of subjects. Calculations on 25 key foods show that 15 of the foods follow in exactly the same hierarchal order of appetite level. The probable errors of the differences show that some foods are quite regular, while other foods show wide differences. In terms of inter-individual variability, appetite levels for many foods show coefficients of variation between 20 and 50 per cent. This degree of regularity is of the same order of individual variation as occurs in other bodily structures, forms, and functions, as for weight of spleen (38.21 per cent for healthy men), dermal sensitivity (35.70 per cent for men and 45.70 per cent for women), and keenness of sight (28.68 per cent for men and 32.21 per cent for women: Pearl, 1923). The characteristic termed appetite level

TABLE 1

Appetite levels of consumption as a means of determining the relative consumer value of different foods
*An example with seven different foods**

SURVEY GROUP NO.†	FOODS	APPETITE LEVELS OF CONSUMPTION IN GRAMS OF FOOD PER DAY ‡										
		(a) *Appetite floors* ‖	(b) *Appetite ceilings* §									
			of the entire population	of the consumer only		of the high average high preference group		of the highest individual record	as related to the degree of preference.			
		X^o	X^p	X^c		X^a		X^{max}	Med.	Good	Very Good	
		M	*M*	*M*	*P.E.*$_M$ *C.V.*	*M*	*P.E.*$_M$ *C.V.*	*M*	*M*	*M*	*M*	*P.E.*$_M$ *C.V.*
	Broccoli											
A 38		10.2	18.4	18.9±1.6	74.1	36.6±2.2	29.9	57	5.7	14.6	24.3±2.2	61.1
B 50			8.5	13.7±1.9	115.1	50.0±5.3	31.3	71	3.9	10.0	24.6±4.0	82.8
C 41			15.0	17.7±1.7	82.7	36.0±2.4	31.4	57	7.3	14.8	25.9±2.7	60.2
	Cabbage											
A		8.0	14.5	14.9±1.2	71.8	23.1±1.4	37.9	41	7.5	9.4	19.7±1.6	54.0
B			10.2	10.6±0.8	80.7	22.1±1.1	27.4	33	4.5	8.5	15.9±1.4	58.2
C			15.1	15.5±1.1	67.6	32.6±2.0	25.8	49	4.0	12.2	21.6±2.1	58.6
	Collards											
A		2.4	0.2	4.5±1.2	55.6	....	..	7	4.5	..	....	..
B			0.4	4.5±1.5	111.1	....	..	14	7.3	..	....	..
C			1.9	9.5±2.1	90.9	14.0±0	..	29	12.3	8.3	14.0±0	0
	Kohlrabi											
A		3.5	2.5	6.5±0.9	79.5	12.6±0.8	22.2	14	3.8	9.5	9.0±2.4	55.6
B			2.1	8.6±2.0	120.3	29.0±0	0	29	3.8	7.2	29.0±0	0
C			5.0	12.5±2.0	96.5	36.0±4.0	23.3	43	9.9	18.0	21.5±3.5	34.4
	Potatoes white											
A		49.5	89.1	91.6±4.5	43.9	120.9±2.0	10.7	171	55.6	82.7	105.5±5.1	32.2
B			80.3	85.4±3.9	46.2	120.7±1.8	10.6	171	44.2	70.4	102.3±4.4	32.9
C			113.9	113.9±6.0	49.4	151.8±6.6	29.6	240	77.0	120.0	114.5±6.8	47.1
	Tomatoes											
A		31.7	58.7	58.7±4.1	62.3	80.2±4.8	40.7	200	..	18.3	70.4±4.2	46.9
B			50.0	51.0±2.9	58.1	77.5±3.3	29.3	145	29.0	37.4	59.1±3.4	49.1
C			65.2	66.9±4.9	66.9	114.3±6.5	31.6	200	17.8	49.0	78.8±6.0	58.1
	Turnips											
A		10.0	16.5	18.5±2.3	105.6	40.5±4.0	49.1	100	4.7	16.6	35.8±5.9	73.1
B			10.7	12.2±0.8	67.0	29.0±0	0	29	8.9	13.9	15.5±1.0	29.0
C			15.1	17.7±1.7	83.7	35.2±2.6	33.1	57	12.9	19.2	28.6±4.7	54.9

TABLE 1 *(Continued)*

Appetite levels of consumption as a means of determining the relative consumer value of different foods
An example with seven different foods *

SURVEY GROUP NO. †	FOODS	RECORD OF PAST EXPERIENCE WITH EACH FOOD				NUTRITIONAL VALUE §					
						(a) Per unit quantity			(b) Per appetite level of X° consumer		
		Never tried Per cent N. T.	*Disliked* Per cent D.	*Tolerated* Per cent T.	*Good or Very Good* Per cent G. & V.G.	Per cent of daily needs Vit. A in 100 gr.	Per cent of daily needs Vit. C in 100 gr.	N. S.** 100 gr.	Per cent of daily needs Vit. A	Per cent of daily needs Vit. C	N. S.**
		M	*M*	*M*	*M*	%	%	*n*	%	%	*n*
	Broccoli										
A 38		0	2.7	0	81.1	180	93	7	34	18	13
B 50		16.0	12.0	14.0	42.0						
C 41		7.5	7.5	2.5	60.0						
	Cabbage										
A		0	0	2.6	92.1	1	143	2	+	21	2
B		0	4.0	2.0	74.0						
C		0	0	2.4	87.8						
	Collards										
A		94.6	0	0	0	124	100	9	6	4	1
B		90.0	0	4.0	0						
C		75.6	4.9	2.4	9.8						
	Kohlrabi										
A		51.4	5.4	13.5	21.6	fair	71	4	+	5	2
B		72.0	4.0	8.0	8.0						
C		45.0	5.0	12.5	15.0						
	Potatoes white										
A		0	0	2.6	84.2	1	40	2	1	37	16
B		0	4.0	2.0	82.0						
C		0	0	0	95.1						
	Tomatoes										
A		0	0	0	94.7	40	39	2	23	23	13
B		0	0	4.0	92.0						
C		0	0	2.4	87.8						
	Turnips										
A		0	2.6	13.2	68.4	+	43	1	+	8	2
B		4.0	8.0	6.0	60.0						
C		0	0	17.1	53.7						

* Refer to following page for footnotes.

is demonstrated by this method of measurement to possess biological regularity worthy of further investigation.

THE REEVALUATION OF FOODS ACCORDING TO APPETITE LEVELS

The chief purpose for which the concept of appetite levels was devised was, as stated previously, to indicate a consumer evaluation nearer the consumer than are the values based on nutrients per 100 grams or any other unit measure of food. The difference in these two measures may be observed by examining the column of Table 1 headed "Nutritional Value".

From these figures one may observe that the seven foods provide different percentages of the daily requirements of vitamins A and C to the consumer and in different relative order of magnitude according to the method of measuring the food (1) in grams or (2) at the desired appetite levels of consumption. For example, when the foods are listed in order of the percentage of the daily vitamin C needs supplied by 100 grams of each food, they rank from highest to lowest as

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FOOTNOTES FOR TABLE 1

* These seven foods were chosen from a total of 63 vegetables in the survey for demonstration purposes only.

† Group A: 38 women, 21 to 50 years of age, Spring, 1942
Group B: 50 women, 21 to 56 years of age, Summer to Fall, 1942
Group C: 41 men, 21 to 55 years of age, Spring to Fall, 1942
All moderately active. Region: Orono, Maine.

‡ *Appetite levels* = the amount of each food that each individual would like to have, if the supply was unlimited, if the food was available all year round, summer and winter, and if the subject could afford to buy it at any time. The consumption rates in grams per day may be reduced to pounds per individual per year by the factor .8.

§ *Nutritional Values* are in terms of the per cent of daily needs according to the standards of the Committee on Foods and Nutrition, National Research Council, 1941, and according to the nutritive values of foods recorded in the 10th Edition of Nutritional Charts, Sept. 1941, of the Research Department of H. J. Heinz Co., Pittsburg, Pa. and used here with their permission.

|| *Appetite Floors* = the amount of each food below which the average consumer cannot go without the necessity for replacement of the loss by an equal calorie value from some other food, in order that the daily calorie value of all 228 foods supply the daily needs (of 2500 calories for Group A). Since all 228 foods will not be consumed in one day, the appetite floors represent long-time lower ranges of values for comparison with the long-time upper ranges of values represented by the *appetite ceilings* of the different consumer groups.

$ *Appetite Ceilings* = the amount of each food indicated as preferred daily by different consumer groups. Since the records on each food represent estimations for each food separately by each subject and cover 228 foods, the average accumulative total quantity for all foods exceeds the total food requirements. This excess is for the group X^p, $1.50X^o$ for X^c, $1.85X^o$, and for X^a, $3.36X^o$ and for X^{max}, $6.86X^o$. The total range between appetite floors of the group and the appetite ceilings of the maximum consumers of each food separately is equal to the ratio of 1 to 6.86 in quantity range. Each food will have its own characteristic appetite floor and ceiling level within these average limits.

** *N. S.* represents the number of nutrients starred or the accumulative value for vitamins A, B, C, and G; minerals calcium, phosphorus, and iron; and nutrients protein and calories, by attributing one star to values above the average for its food class and another for values above the average for the entire group of 228 foods. The maximum N. S. is therefore two for each nutrient and 18 for all nutrients. N. S. is above average for all nutrients and N. S. 0 is below average for all nutrients listed. An N. S. value of 0 or of low value does not imply a total lack of nutritional value; other nutrients as yet not placed in the standard may raise some of these to a high value.

follows: Cabbage 143 > collards 100 > broccoli 93 > kohlrabi 71 > turnip 43 > potato 40 > tomato 39 per cent of the daily requirements of ascorbic acid. On the other hand, when the same vitamin C values are calculated according to *appetite level,* the hierarchal order of value is very different, as follows: Potato 37 > tomato 23 > cabbage 21 > broccoli 18 > turnip 8 > kohlrabi 5 > collards 4 per cent of the daily requirements of ascorbic acid.

It will be seen that some striking changes take place in the relative order of importance of each food when appetite levels are used in the measurement of value. Specifically potatoes and tomatoes, which are at the bottom of the serial order of value when the foods are compared on the basis of vitamin C per unit quantity, are raised to first and second place when comparison is on an appetite basis. Collards, not widely recognized in this Northeast region, are thrown from *first* place down to *last* place. This reversal in the relative nutritional value of each food depends on whether appetite levels have been considered in the comparison.

In order to provide a more balanced or composite nutritional evaluation for each food, rather than a comparison based upon one nutrient at a time, the foods have been given a star for each of the nine nutrients they possess at a level above the average for their respective food class and another star for a value above the average for the entire group of 228 foods. These N. S. values (nutrients starred) reach a maximum of 18 for a food above the average in both respects and for all nine nutrients.

Upon this basis of evaluating foods, a similar reversal in order takes place according to the method of comparison. When compared solely on the basis of the group of nutrients supplied in 100 gram quantities (see list in Table 1), collards stand first with nine N. S. values. When the comparison includes appetite levels as a point of reference, potatoes move up from a position next to last to first with 16 N. S. values, and tomatoes also move up from a position next to last to second with 13 N. S. values (tying with broccoli which remains second). Collards, on the contrary, move down from first position to last with only 1 N. S.

From the listing of N. S. values for all 228 foods upon the basis of appetite levels of consumption, ***whole milk*** stands out as the only food which attains the maximum rating of 18 nutrients above the average. The 24 highest foods in order of composite nutritional value

according to appetite levels of the consumers who give the food a high-average, high-preference rating (X^a) include the following:

18 N. S. whole milk (466 grams per day)

17 N. S. green peas (68), evaporated milk (153)

16 N. S. beef liver (31), eggs (51)

15 N. S. mustard greens (40), dried prunes (42), skim milk (306)

14 N. S. dandelion greens (45), oranges (114), whole wheat bread (63), beefsteak (62), sweet potatoes (76), white potatoes (121), water cress (43)

13 N. S. broccoli (37), muskmelon (112)

12 N. S. yams (66), strawberries (63), white bread (49) beef loin (50), tomatoes (80), wheat germ (12), beef sweetbreads (40).

Thus the inclusion of appetite levels as a point of reference sorts out of the foods already known to be of high nutritional value per unit weight those foods which are also highly preferred and consumed at a high rate. Both factors must be included in giving foods a relative nutritional value from the consumer point of view.

Foods classified as low in nutrients may be excellent sources of nutrients at high appetite levels

This demonstration by means of seven selected foods may be carried on into practice in the examination of almost any list of foods recommended as *excellent* or *poor* sources for vitamins. Taken as an example, a recent (1942) compilation of some 53 representative foods analyzed for B vitamins include as *poor* sources of thiamin the following: Processed cereals, whole milk, beef muscle, and fresh peaches. The thiamin content of all of these foods is low, as compared with lean pork loin, when merit is judged as it is on the basis of thiamin *content per gram*: .05 to .78 γ/gm. on the fresh weight basis as compared with the value of 7.7 γ/gm. for lean pork loin, and .19 to 3.6 γ/gm. on the dry weight basis as compared with 28 γ/gm. for lean pork loin (Cheldelin and Williams, 1942). On the other hand, when these same foods are adjudged on the basis of the percentage of the daily thiamin needs con-

tributed by these foods at average appetite levels, one discovers that some of these foods supply a significant percentage of the daily thiamin requirements and are in truth among the *highest* contributors of thiamin to the actual diet (see Table 2). Whole milk, for instance, with 0.44

TABLE 2

*A list of the 14*highest contributors of thiamin to the diet on the basis of appetite levels of consumption*

PER CENT OF 500 I. U. OF THIAMIN		APPETITE LEVELS FOR X^a CONSUMERS † IN GRAMS OF FOOD PER DAY
Per cent		*Grams*
32%	Yeast, fresh	14
27	Wheat germ	12
21	Pork Chops	23
18	Green peas	68
15	Ham, fat	16
15	Whole wheat bread	63
11	Whole milk	466
10	White potatoes	121
10	Skim milk	366
9	Beef sweetbreads	40
9	Beef steak	62
8	Chard leaves	25
7	Rye bread	52
7 (14th)	Beef loin	50
5 (25th)	Eggs	51
4 (35th)	Apples	119

* 14 out of the total of 228 foods.

† X^a consumers are those who classify the food as *good* or *very good* and who indicate a consumption rate above the average of this group.

γ/gm. of thiamin (fresh weight basis) stands eighth from the lowest in the list of 61 foods tested by Cheldelin and Williams, but when appetite levels are considered and we proceed according to the X^a consumption rate of 466 grams of milk (about one pint) per day, milk stands first among the dairy products and seventh highest of all 228 foods, in our

survey, as a source of thiamin. Lean beef, as beef steak (62 grams per day) and beef loin (50 grams per day), stands third and fifth highest among the meats as a source of thiamin. Eggs and apples also tested low in thiamin per unit weight; but eggs would become at a potential appetite level of 51 grams (about one egg) per day the seventh best source of thiamin in its class, and apples at a level of 119 grams would rank fifth highest among the fruits. Without reference to appetite levels of consumption, these excellent sources of thiamin would be disregarded as poor.

One may glance through the final summary of foods listed for riboflavin, niacin, pantothenic acid, pyridoxin, biotin, inositol, and folic acid and discover for several of the items that foods of high appetite level, such as milk, eggs, apples, and lean beef, are classified as poor sources of a number of these nutrients. Upon analysis in terms of appetite levels these foods, except for those exceedingly low, will be found to move out of the class of poor sources they are in to join the group of foods considered good or better sources.

Foods classified as high in nutrients may be poor sources of nutrients at low appetite levels

The classification of foods as good or poor sources of a nutrient on the basis of unit weight contains another error from the consumer point of view: Not only will foods of high nutritive value fail to contribute much to the diet if the appetite level is low, as was shown with collards, but the lists of best sources may fail to include many foods which appetite levels would indicate should be so classified. In the list previously referred to, the *best sources* of thiamin were stated as pork, green vegetables, tomatoes, grapefruit, and wheat germ. Whole wheat bread and white potatoes were omitted, and yet they are, when evaluated as in this survey in terms of appetite levels (63 grams and 121 grams respectively), sixth and eighth highest of all 228 foods as sources of thiamin to X^a consumers, supplying 15 per cent and 10 per cent respectively of the daily thiamin needs.

The complete list of foods rated by N. S. values (note the partial list given earlier in this paper), together with the listing by specific nutrients separately, should form some basis for the biological engineering referred to in the introduction, since the foods are rated in serial order according to both their special and their composite nutritional con-

tribution to the consumer as of to-day at the rate he (this one group) prefers to consume them. It is pointed out that with subsequent correctives applied to problem-foods, and problem-subjects, and problem-regions, and with a proper weighting for the appetite levels of different consumer groups, the foods in the list will shift somewhat in their order. But even as they stand at present, they represent a biologically oriented placement.

With appetite levels considered, a low rating may indicate, as stated before, a low consumption rate which may be corrected later by the use of the appropriate educational or economic corrective. Furthermore, a low N. S. rating indicates a low value only for the 9 nutrients on which widely accepted human standards are available. With each addition of other nutrients to the N. S. rating, foods now rated 0 or of low value might shift to different levels. For example, mushrooms, high in vitamin B_1, P, and Fe with a medium N. S. value according to these records, is now reported as first in nicotinic acid, third in riboflavin and in pantothenic acid and fourth in biotin per unit weight (Cheldelin and Williams, 1942), which facts, taken together with the relatively high consumer appetite level of 51 grams, might raise the relative nutritional value of mushrooms far above its present combined nutritional rating.

Finally sight should not be lost of the numerous foods valued for their *few* specific nutrients. Theoretically there is evidence to support the necessity for these partially specialized foods as one means of securing variety for the omnivorous human consumer after he is supplied first with foods classified as nutritionally broad.

APPETITE FLOORS AND CEILINGS

Since the records were secured in terms of appetite levels for each food and for each individual separately, the sum of the levels recorded for all 228 foods would obviously exceed the total amount of food any one individual would consume in any one day. The total daily food consumption indicated by each of the four consumer subgroups was as follows: For X^p, 3119 grams; for X^c, 3897 grams; for X^a, 6984 grams; and for X^{max}, 14389 grams. In order to determine how far in excess of any one individual's daily needs these quantities of food might be, one may refer to the calorie content of these same foods at the appetite levels of each consumer group. Calculations were

made on the first three subgroups of consumers for Survey A; the following results in terms of the percentage of daily calorie needs (2500 calorie per day) were secured: For X^p, 150.52 per cent; for X^c, 185.16 per cent; and for X^a, 335.94 per cent. These factors then may be used to reduce the quantities of food indicated in the appetite levels for each food so that the daily grand total of food consumed does not exceed the daily need of 2500 calories for this group A. These values we have termed the *appetite floors* (appetite floor = the amount of each food below which the average consumer cannot go without the necessity for replacement of the loss by an equal calorie value from some other food), since failure to consume the amount indicated for any one food at its own particular appetite floor level will require a greater consumption of some other food or foods in order to keep the daily calorie consumption up to the daily needs of 2500 calories. On the other hand, the appetite levels of the different subgroups of consumers represent *appetite ceilings* (appetite ceiling = the amount of each food indicated as preferred daily by different consumer groups) for each food separately, since they represent a rate of consumption which cannot be maintained for *all* foods without exceeding the daily calorie needs and yet they represent rates of consumption for individual foods desired by a certain proportion of the population.

Appetite floors and appetite ceilings, then, indicate the range of acceptance for any one food. While the group might be encouraged, when necessary in emergency, to consume an amount of any one abundant food equal to that indicated by the X^a consumers, it might not be possible to expect all individuals of the group to consume an amount above that indicated by the maximum consumer (X^{max}) without physiological or psychological distress. On the other hand, any consumption rate for any one food below the appetite floor must be made up with some other substitute food. Therefore appetite floors and ceilings may serve as the lower and upper limits or the snubbers to the variation and freedom necessary for good appetite and good nutrition.

APPETITE LEVELS AND THE DEGREE OF PREFERENCE

Examination of the seven demonstration foods in the column headed "Past Experience" (Table 1) shows that higher degrees of preference are associated with higher appetite levels. For all 183 foods [2] the ratio

[2] Only 183 of the 228 foods in the survey had records for all three degrees of preference.

between the three degrees of preference was 1 : 2½ : 5. The degree of preference, then, modifies appetite levels five fold in comparison with the 3.36 fold and 6.86 fold for X^a and X^{max} consumer ceilings above appetite floors.

The appetite levels for each class of food differ widely both between classes and within classes of foods. Fruits as a rule show higher appetite levels than vegetables, and yet the appetite level for potatoes is higher than that for any other solid food, with apples a close second. Cereals are low. Nuts are consistently low as a class and show the lowest appetite levels of all foods with an average of four kinds registered for the three degrees of preference as 1.0, 2.0, and 4.2 grams per day. Within the class of dairy produce, whole milk, a liquid, shows appetite levels of 100, 206, and 346 for the three degrees of preference; the concentrated milk product, American cheese, on the other hand, has values of 3.0, 5.6, and 11.3.

In connection with the analysis of "degrees of preference" and of "past experience with food", several possible fields of study are uncovered by the survey. Such studies may appear to have special significance chiefly for the region of the survey but since the subjects were born and reared in 24 different states, the comparison of foods on the basis of their preferences and prejudices provides the link between local and national aspects of the problem. Some of the potentialities residing in such a survey of appetite levels will be mentioned here briefly; for further analysis of the problems cited below, reference must be made to the complete report.

The variation in degree of preference for different foods not only draws attention to foods of superior nutritional merit which might otherwise be missed, and to foods of superior gustatory merit, but also exposes the problem-foods. Thus, in this list of seven foods (Table 1), collards is a problem-food, and together with kohlrabi is unknown to a large part of the population tested. Not only had 95 per cent to 51 per cent of the population never tried the foods but the degree of preference by those who had tried them was not high. This does not imply that collards or kohlrabi is important but that problem-foods and the nature of the problem may be indicated by records of past experience. Some foods may be of importance, others of no importance at all.

On the other hand, some foods have been tried by everyone, and of these the turnip is not so highly preferred as is the tomato, which

also has been tried by everyone. Eighty-eight to 95 per cent consider the tomato as good to very good, while only 68 per cent consider the turnip in the same preferred class. These differences in degree of preference are reinforced by the relative differences in the percentage of the subjects who tolerate or dislike the same foods.

Of the list of problem-foods never tried by the subjects in this survey both Taro and Yellow Yautia were unknown to all 129 subjects. Other foods high in percentage *not* tried included: Collards, 95; papayas, 85; whey, 85; goatmilk, 80; lamb's quarters, 80; mangoes, 80; guavas, 75; leeks, 75; beef brains, 70; clams, 70; soybeans, 70. Among the foods of low trial value is lamb's quarters, and yet this 'weed' is abundant in the region of the survey, is consumed as a spring green by many who have lived long in the region, and is rated by those who have tried it and who like it (X^a consumers) as eleventh best source of vitamin A. It is also significant to note that among the meats the chief problem-foods in terms of the percentage who have never tried them include beef brains, 70 per cent; kidney, 60 per cent; sweetbreads, 50 per cent; beef heart, 40 per cent; some of them represent, nevertheless, at X^a appetite levels excellent sources of vitamins B and G and of phosphorus.

Among the highly preferred foods (90 per cent or above, and tried by everyone) we find the following percentages: Butter, 100; pecans, 100; beefsteak, 95; carrots, 95; devil's food cake, 95; green corn, 95; oranges, 95; sweet chocolate, 95; tomatoes, 95; walnuts, 95; cabbage, 92; bacon, 90; cashews, 90; grapes, 90; ice cream, 90; peanuts, 90; pineapples, 90; pork chops, 90; red raspberries, 90; strawberries, 90; brown and granulated sugar, 90; tangerines, 90; turkey, 90.

On the other extreme, foods with the lowest preference ratings for each food class and tried by everyone include the following percentages: Succotash, 40; baked beans, 45; sauerkraut, 45; parsnips, 50; summer squash, 50; cottage cheese, 50; codfish, 55; frankfurters, 55; oysters, 55; sardines, 55; dried figs, 60; oatmeal, 60; blackberries, 65; tapioca, 65; honey, 65; doughnuts, 65; tomato ketchup, 65; peanut butter, 65; dried coconut, 70.

For a different sex or age group, these preferences may be altered. Sex differences may be noted by the larger appetite levels of the men as against the women and in the differential degree of preference (e. g. note potatoes and tomatoes). For the same degree of preference as that of X^a consumers, sex differences in appetite levels are diminished.

Some of the differences are in the food, however, and succotash (40 per cent), the lowest of the vegetables, is made from lower grade corn, while green corn by contrast stands highest (95 per cent) in the list of preferred vegetables.

Regional experiences are expressed in the bimodal records of the subjects in the nature of their acquaintance with foods like the raspberry. The Black raspberry is known and preferred chiefly by those born and reared outside the state while the Red raspberry is known and preferred by the subjects who are native to both regions. Other foods not grown in the region and of little import value, like leeks, papayas, soybeans, hickory nuts and black walnuts, are among the foods of low trial value.

These differences in preference for the different food crops may indicate the necessity on the one hand for education or better food preparation for the subject, or on the other hand attention to genetic selections for higher palatability or for higher adaptability to the region in the varieties of these particular food crops. The use of appetite levels could expose much information on food habits and point out food difficulties in terms of specific problem foods and in terms of the nature of the adjustment.

IS APPETITE A GUIDE TO GOOD NUTRITION?

In addition to the foregoing observations on the necessity for a recognition of appetite levels in evaluating different foods, one of the significant results of the study comes out of the calculations on *appetite floors,* i. e. that appetite floors make possible an estimation of the degree to which appetite may be used effectively as a guide in nutrition if the consumers are given full opportunity for self-expression. In other words, if we reduce the records of total daily food consumption of these normally active mature subjects to supply calorie needs at a 100 per cent level, this question arises: Has the selection of foods according to appetite supplied the consumer with daily requirements for any or all of the eight vitamins and nutrients besides calories? The answer to this question has been secured for Survey Group A on consumer subgroups X^p, X^c, and X^a by separate calculations for all nine nutrient values and for all 228 foods. A summary of these values is presented in Table 3.

TABLE 3

The per cent of the daily nutritional requirements secured when appetite levels are used as guides *

CONSUMER SUB-GROUP	TOTAL ACCUMULATIVE APPETITE LEVELS FOR ALL 228 FOODS		APPETITE LEVELS REDUCED SO THAT DAILY CALORIE NEEDS ARE 100 PER CENT OR 2500 CALORIES		PER CENT OF DAILY REQUIREMENTS FOR 8 IMPORTANT NUTRIENTS WHEN APPETITE LEVELS FOR TOTAL DAILY FOOD CONSUMPTION ARE REDUCED TO EQUAL THE DAILY NEEDS OF 2500 CALORIES, I. E. 100 PER CENT							
	Grams of food per day per capita	Per cent of daily calorie needs	Grams of food per day per capita	Per cent of daily calorie needs	Vitamins				Minerals			Protein
					A	B	C	G	Ca	P	Fe	
X[b]	3119	150.5	2072	100	440	139	558	119	155	245	217	170
X[c]	3897	185.2	2105	100	508	157	570	129	176	265	222	175
X[a]	6984	335.9	2079	100	460	153	583	127	177	259	223	171

* Survey group A: women, 21-50, moderately active; Spring, 1942; Region, Orono, Maine.

From the figures in Table 3 one will observe that when the appetite levels have been reduced to a normal calorie consumption rate (based on 100 per cent calorie needs), the average individual of the group* secures far more than 100 per cent of his needs for all other eight nutrients. The excess will perhaps meet all reductions which may have to be made for partial physiological unavailability of any of the nutrients in any of the foods and will serve to counterbalance some of the low-nutrient values in food-mixtures after processing or cooking. Some of the nutrients were secured in excess several fold, as with vitamin C

* Individual differences as related to body build, physical condition, and appetite levels will be presented in a later report.

four to five fold. Other nutrients, as the B vitamins, were secured in excess by less than one fold. The four nutrients with the least excess were vitamin G, 19 to 20 per cent[4]; vitamin B_1, 39 to 57 per cent; calcium, 55 to 77 per cent; and protein, 70 to 75 per cent in excess of daily needs. The four nutrients with the greatest excess were vitamin C, 458 to 483 per cent; vitamin A, 340 to 408 per cent; phosphorus, 245 to 265 per cent; and iron, 217 to 223 per cent in excess of daily needs.

Appetite levels of those who consider the food *very good* (X^{vg}) would indicate a greatly increased rate of consumption of some fruits, as for example: Oranges, 89 grams per capita per day; apples, 87; watermelons, 79; cantaloupes, 77; muskmelons, 75; tomatoes, 70; and honeydew melons, 63. The appetite levels for these fruits were exceeded only by potatoes and milk. A high rate of consumption was also indicated for leafy greens like lettuce, 55 grams per capita per day; watercress, 49; dandelion greens, 43; and mustard greens, 40. Other highly preferred foods include whole wheat bread, 48 grams; beefsteak, 45; eggs, 42; ice cream, 63; and buttermilk, 57. Such highly preferred foods desired at high appetite levels are largely responsible for the provision of nutrients above 100 per cent of requirements; and the methods required to encourage their production and distribution or to increase their accessibility represent a problem in food economics.

These observations on appetite emphasize again (Dove, 1934, p. 268) and in a new manner the fact that access to a wide variety of natural foods (Dove, 1939, p. 160) may play a highly significant rôle in limiting the world-wide incidence of malnutrition. Thus while the appetites of individuals taken separately are not infallible guides to good nutrition, nevertheless the appetite levels and preferences of groups of healthy, active individuals may serve as one of the advance guides to the nutrition of the future (Dove, 1938).

SUMMARY

A technique has been devised for use in food habit studies whereby psychological measures of value are combined with nutritional measures of value under the end-result termed *appetite levels* of consumption.

[4] This low value for vitamin G may be due in part to a lack of values on 39 of the 228 foods.

In three preliminary surveys, appetite levels demonstrate a statistical consistency comparable with the consistency in weight of organs and measures of sensitivity in the human subject.

When simple natural foods are compared in terms of their nutritional contributions at appetite levels of consumption, they take on an entirely different order of value: Foods classified as poor sources according to nutrients per unit measure or weight may come to be classified, on the basis of appetite levels, as excellent sources, and vice versa.

Appetite floors and ceilings were defined to represent the lowest and highest rate of consumption for each food—a rate which, if not met or if exceeded, will involve substitutions. Between appetite floors and ceilings, food production planning may work within the range of consent of the consumer.

Appetite levels of each food, as indicated by individuals separately and in subgroups, make possible the detection of problem foods (food unpalatable or of low gene-nutrient value), of problem subjects (subjects who are allergic to or who dislike or who never try certain foods), and of problem phases of food economics.

When appetite levels for all 228 foods used in a preliminary survey are reduced to meet the calorie need of the subjects 100 per cent, these same foods supplied the average consumer with more than 100 per cent of vitamins A, B_1, C, and G; of the minerals calcium, phosphorus, and iron; and of protein. Even though each individual's appetite levels would differ from the average, and even though mixtures of the same foods processed would lower the nutrient values, yet as a bio-economic problem malnutrition would appear to secure some of its chief correctives and preventives through a wider availability of foods possessing original nutrient values and in a pattern more nearly adjusted to appetite levels of groups of normal healthy individuals.

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THE STATISTICAL DIAGNOSIS OF ZYGOSITY IN MULTIPLE HUMAN BIRTHS

BY MEINHARD ROBINOW, M.D.

The Department of Pediatrics, University of Georgia School of Medicine, Augusta, Georgia, and the Samuel S. Fels Research Institute, Yellow Springs, Ohio

I. INTRODUCTION

DISCORDANCE for any trait which is determined entirely on a genetic basis (sex, blood groups, etc.) proves unequivocally dizygotic origin. Concordance for such traits does not establish the diagnosis of monozygosity with equal certainty. But concordance for all and discordance for none of many traits tested makes it very likely that twins or triplets are monozygotic. In practice, the diagnosis of monozygosity is frequently made by inspection. Experience has shown that twins frequently show the striking resemblance which is implied by the term "identical". Experience has further shown that such marked similarity occurs only between the members of a set of monozygotic twins or triplets. In other words, the striking similarity of features is due to concordance in a great many independent traits. The likelihood that fraternal twins are concordant in so many traits is so remote that the diagnosis of monozygosity is justified in these cases. However, there are cases in which resemblance between members of a set is less striking and in which the diagnosis cannot be made by inspection. Conversely, discordance for some trait of special interest as club feet, diabetes or dementia precox may throw doubt on a diagnosis of monozygosity based on resemblance of features. These cases, if proven monozygotic, are of particular interest since the discordance demonstrates the extreme effects of pre- and post-natal environment. In such instances it may be helpful to use the quantitative statistical approach to be presented here.

II. TWINS OF SPECIFIED PARENTAGE

It is possible to determine the probability p_f (a) that fraternal twins (or two siblings) show a given trait (a). This may be illustrated by the inheritance of blood groups in the following three families:

Parents	(1) A × A	(2) A × O	(3) O × O
Children	O, O	O, O	O, O

In family (1) both parents belong to the phenotype A. Their genotype must be AO since they have O offspring. The probability of group O offspring is 1/4, the probability of group A offspring is 3/4. If these parents have fraternal twins (or two single children) the expected proportions will be: 1/16 O/O (both children group O) = p_f(O), 6/16 A/O (one child group O, the other group A), and 9/16 A/A (both children group A) = p_f (A). 1/16 + 9/16 = 5/8 of the pairs would be concordant for one or the other type = p_f (A or O).

One can now answer the question: how frequently are fraternal twins concordant for a given trait? However, the more pertinent question is: what is the probability p (M) that twins, concordant for a given trait, are monozygotic? This question can be answered by the following formula:

$$p(\mathrm{M}) = \frac{I \cdot p_i}{I \cdot p_i + F \cdot p_f} = \frac{1}{1 + \frac{F \cdot p_f}{I \cdot p_i}}.$$

Here p_i is the probability that identical twins are concordant for a given trait; I and F are the respective frequencies of identical and fraternal twins in the general population. $\frac{F}{I}$ is a constant which can be estimated by Weinberg's method (1) from the excess of like-sexed over unlike-sexed twins. Its numerical value, calculated from U. S. census figures (2) is 2.9. The formula may be further simplified by substituting the symbol s for $\frac{p_f}{p_i}$:

$$p(\mathrm{M}) = \frac{1}{1 + 2.9 \cdot s},$$

and the probability that twins are fraternal:

$$p(\mathrm{D}) = 1 - p(\mathrm{M}).$$

One can now determine values for s in family (1):

$$s(\mathrm{O}) = \frac{p_f(\mathrm{O})}{p_i(\mathrm{O})} = \frac{1/16}{1/4} = 1/4,$$

$$s(\mathrm{A}) = \frac{p_f(\mathrm{A})}{p_i(\mathrm{A})} = \frac{9/16}{3/4} = 3/4,$$

$$s(\mathrm{A\ or\ O}) = \frac{p_f(\mathrm{A\ or\ O})}{p_i(\mathrm{A\ or\ O})} = \frac{5/8}{1} = 5/8.$$

For families (2) and (3) s becomes accordingly:

$$\text{family (2)}: s(\mathrm{O}) = 1/2,\ s(\mathrm{A}) = 1/2,\ s(\mathrm{A\ or\ O}) = 1/2,$$
$$\text{family (3)}: s(\mathrm{O}) = 1,\ s(\mathrm{A}) = 1,\ s(\mathrm{A\ or\ O}) = 1.$$

The probability of two independent events occurring simultaneously is the product of the probabilities of each event occurring separately. The probability s (O, ♀) of fraternal twins in family (1) being both females and both having blood group O is accordingly:

$$\frac{p_f(\mathrm{O}) \cdot p_f(♀)}{p_i(\mathrm{O}) \cdot p_i(♀)} = s(\mathrm{O}) \cdot s(♀) = 1/8.$$

For the twin pairs in families (2) and (3) s (O) $\cdot$ s (♀) becomes 1/4 and 1/2, respectively.

The general formula for p (M) may now be written:

$$p(\mathrm{M}) = \frac{1}{1 + 2.9\ [s(\mathrm{a}) \cdot s(\mathrm{b}) \cdot s(\mathrm{c}) \ldots\ldots \cdot s(\mathrm{n})]}.$$

Tests for additional traits may be made until either discordance proves dizygosity or until p (M) has reached an arbitrary limit deemed adequate, say .990 or .999.

III. UNSPECIFIED PARENTAGE

While it is obviously desirable to obtain information on the relatives of twins, such information is not always available. In such cases p_f and s can be deduced by application of the principle of random mating. This is demonstrated in Tables 1 and 2 for various types of inheritance.

TABLE 1

Derivation of expected concordance frequencies in random pairs of sibs or fraternal twins

1. Traits dependent on a single pair of autosomal genes with complete dominance of one allele.

(1) Type of mating	(2) Frequency of specified matings	(3) Frequencies of indicated phenotype combinations among progeny pairs from each type of mating			(4) = (2) · (3a) Frequency of D/D pairs among progeny of (1) from all matings	(5) = (2) · (3c) Frequency of R/R pairs among progeny of (1) from all matings
		(a) D/D	(b) D/R	(c) R/R		
AA · AA	p^4	1	..	..	p^4	..
AA · Aa	$4p^3q$	1	..	..	$4p^3q$	..
AA · aa	$2p^2q^2$	1	..	..	$2p^2q^2$	..
Aa · Aa	$4p^2q^2$	$\frac{9}{16}$	$\frac{6}{16}$	$\frac{1}{16}$	$\frac{9}{4}p^2q^2$	$\frac{1}{4}p^2q^2$
Aa · aa	$4pq^3$	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{1}{4}$	pq^3	pq^3
aa · aa	q^4	..	..	1	..	q^4
	Totals:				$\frac{p}{4}(4 + 5p - 6p^2 + p^3) = p_f(\mathrm{D}) =$ probability that both members of a random pair of fraternal twins will exhibit the dominant trait. $p_i(\mathrm{D}) = p^2 + 2p(1-p)$ $\frac{p_f(\mathrm{D})}{p_i(\mathrm{D})} = s(\mathrm{D}) = \frac{4 + 5p - 6p^2 + p^3}{8 - 4p}$	$\frac{1}{4}q^2(1 + q)^2 = p_f(\mathrm{R}) =$ probability that both members of a random pair of fraternal twins will exhibit the recessive trait. $p_i(\mathrm{R}) = q^2$ $\frac{p_f(\mathrm{R})}{p_i(\mathrm{R})} = s(\mathrm{R}) = \frac{(1 + q)^2}{4}$

The probability that both members of a random pair of fraternal twins will be concordant for either one or the other of the traits, R or D, $= p_f(\mathrm{R}) + p_f(\mathrm{D})$. And, since $p_i(\mathrm{R}) + p_i(\mathrm{D}) = 1$, $s(\mathrm{R\ or\ D}) = p_f(\mathrm{R}) + p_f(\mathrm{D}) = 1 - 3/2\ q^2 + q^3 + 1/2\ q^4$.

TABLE 2

Derivation of expected concordance frequencies in random pairs of sibs or fraternal twins

2. Traits dependent on a single pair of autosomal genes; heterozygote identifiable.

(1) Type of mating	(2) Frequency of specified mating	(3) Frequencies of indicated genotype combinations among progeny pairs from each type of mating			(4) = (2) · (3a) Frequency of MM/MM pairs among progeny of (1) from all matings	(5) = (2) · (3b) Frequency of MN/MN pairs among pairs from all matings	(6) = (2) · (3c) Frequency of NN/NN pairs among pairs from all matings
		(a) MM / MM	(b) MN / MN	(c) NN / NN			
MM · MM	p^4	1	..	..	p^4	..	..
MM · MN	$4p^3q$	$\frac{1}{4}$	$\frac{1}{4}$	..	p^3q	p^3q	..
MM · NN	$2p^2q^2$	..	1	1	..	$2p^2q^2$	..
MN · MN	$4p^2q^2$	$\frac{1}{16}$	$\frac{1}{4}$	$\frac{1}{16}$	$\frac{1}{4}p^2q^2$	p^2q^2	$\frac{1}{4}p^2q^2$
MN · NN	$4pq^3$	..	$\frac{1}{4}$	$\frac{1}{4}$	..	pq^3	pq^3
NN · NN	q^4	..	..	1	..	..	q^4
Totals:					$\frac{1}{4}p^2(1+p)^2$ = p_f(MM) = probability that both members of a fraternal pair will be homozygous for allele M, frequency p. p_i(MM) = p^2 s(MM) = $\frac{(1+p)^2}{4}$	$pq + p^2q^2$ = p_f (MN) = probability that both members of a fraternal pair will be heterozygous. p_i (MN) = $2pq = 2p(1-p)$ s(MN) = $\frac{1+p-p^2}{2}$	$\frac{q^2(1+q)^2}{4}$ = p_f(NN) = probability that both members of a fraternal pair will be homozygous for allele N, frequency q. p_i(NN) = q^2 s(NN) = $\frac{(1+q)^2}{4}$

The probability that both members of a fraternal pair will be concordant for either MM, MN, or NN is given by the sum of columns (4), (5), and (6); and

$$\frac{p_f(\text{MM}) + p_f(\text{MN}) + p_f(\text{NN})}{p_i(\text{MM}) + p_i(\text{MN}) + p_i(\text{NN})} = s(\text{MM or MN or NN}) = \frac{2 - 4p + 7p^2 - 6p^3 + 3p^4}{2}$$

A. Traits dependent on diallelic autosomal factors

Table 1 shows the derivation of formulae for concordance-probabilities in terms of the respective population-frequencies, p and q, of two alleles one of which is completely dominant to the other. The algebraic value of $s(D)$, at the foot of column 4, gives the ratio of the probability, $p_f(D)$, that both members of a pair of fraternal twins (or sibs) will exhibit the dominant trait, to the probability, $p_i(D)$, that it will be exhibited by a pair of identical twins; $s(R)$, at the foot of column 5, is the corresponding ratio between the probabilities of concordance with respect to the recessive trait. Finally, $s(R \text{ or } D)$ is the ratio of fraternal-twin concordance to identical-twin concordance without specification as to the phenotype exhibited:—since identical twins must be concordant either for the dominant or for the recessive trait, the denominator in this ratio is unity, and $s(R \text{ or } D)$ is the same as $p_f(R \text{ or } D)$—that is, the probability that both members of a fraternal pair exhibit one or the other of the alternative phenotypes.

It will be seen that the usefulness of a particular trait for testing twin-zygosity is a function of the population-frequency of the gene on which the trait depends. Thus, in the case of the alleles which determine the presence or absence of the Rh-agglutinogen, p, the frequency of the dominant gene (presence of agglutinogen) is approximately .61, and q, the frequency of its recessive allele, .39 (9), so that

$$s(D) = .907$$
$$s(R) = .483;$$

that is, concordance with respect to the rarer recessive phenotype has greater weight toward excluding the likelihood of dizygotic origin than does concordance for the dominant phenotype. The minimal and maximal values of s in the case of traits determined by autosomal factor-pairs are as follows:

$s(D)$ approaches .5, as p approaches 0;	$s(D) = 1$, when $p = 1$.
$s(R)$ approaches .25, as q approaches 0;	$s(R) = 1$, when $q = 1$.
$s(D \text{ or } R) = .728$, when $p = .31$;	$s(D \text{ or } R) = 1$, when p or $q = 1$.

In Table 2, concordance-probability formulae are derived for traits which depend on two alleles without dominance, so that the heterozygotes are identifiable. The application of these formulae may be illustrated with the M and N bloodtypes.

The incidence of the genes M and N in the general population is

approximately .55 and .45 respectively (3). These frequencies give the following values for s:

$$s(\mathrm{MM}) = .601$$
$$s(\mathrm{MN}) = .624$$
$$s(\mathrm{NN}) = .526$$

Recognizable heterozygotes are valuable for zygosity diagnosis almost irrespective of the gene frequency. If p approaches 1 or 0, $s(\mathrm{MN})$ approaches a minimum value of .5; if $p = .5$, $s(\mathrm{MN})$ reaches its maximum .625.

B. Triple alleles

The four blood groups depend on three allelic genes: A and B, neither of which is dominant over the other, but each of which is dominant over the third, O. The calculations of p_f and s, though identical in principle with the foregoing, become somewhat more complex and will not be given in detail.

The following formulas are obtained:

$$s(\mathrm{A}) = \frac{4p^3 + 4p^2q + 16\,p^2r + 12pqr + 17pr^2 + 6qr^2 + pq^2 + 2q^2r + 4r^2}{4p + 8r}$$

$$s(\mathrm{B}) = \frac{4q^2 + 4pq^2 + 16q^2r + 12pqr + 17\,qr^2 + 6pr^2 + p^2q + 2p^2r + 4r^2}{4q + 8r}$$

$$s(\mathrm{AB}) = \frac{2p^2 + 3pr + r^2 + 6pq + 3qr + q^2}{4}$$

$$s(\mathrm{O}) = \frac{(p + q + 2r)^2}{4}$$

Assuming the following gene frequencies (4):

$$f(\mathrm{A}) = p = .259$$
$$f(\mathrm{B}) = q = .073$$
$$f(\mathrm{O}) = r = .670$$

one obtains the numerical values:

$$s(\mathrm{A}) = .679$$
$$s(\mathrm{B}) = .489$$
$$s(\mathrm{AB}) = .342$$
$$s(\mathrm{O}) = .699.$$

C. *Sex-linked traits*

Similarly one obtains for a sex-linked factor (x = recessive gene; p = frequency of x):

	If p approaches 0 s approaches	*If p approaches 1 s approaches*
$s(xx) = \frac{1+p}{2}$	0.5	1.0
$s(Yx) = \frac{1+p}{2}$	0.5	1.0
$s(XX \text{ or } Xx) = 1 - \frac{p^2}{2+2p}$	1.0	0.75
$s(YX) = 1 - \frac{p}{2}$	1.0	0.5

IV. ZYGOSITY DIAGNOSIS OF TRIPLETS

There are three types of triplets: monozygotic, dizygotic and trizygotic. The probability that monozygotic triplets are concordant for a given trait (allele not specified) is 1, for a given allele = p_i. The probability that dizygotic triplets are concordant is s or p_f, the probability that trizygotic triplets are concordant is s^2 or p_f^2.

It is therefore usually not difficult to exclude monozygotic origin by demonstrating at least one instance of discordance or to make trizygotic origin highly unlikely by showing concordance for many independent traits.

If all three members of a set are concordant for a certain number of traits the decision usually rests between monozygotic and dizygotic origin. The probabilities may be formulated as follows:

$$p(m) = \frac{M \cdot p_i}{M \cdot p_i + D \cdot p_f + T \cdot p_f^2} = \frac{1}{1 + \frac{D}{M} \cdot s + \frac{T}{M} \cdot s \cdot p_f} = \frac{1}{1 + s(1.4 + 1.7\, p_f)}$$

$$p(d) = \frac{D \cdot p_f}{M \cdot p_i + D \cdot p_f + T \cdot p_f^2} = \frac{1}{1 + \frac{M}{D} \cdot \frac{1}{s} + \frac{T}{D} \cdot p_f} = \frac{1}{1 + \frac{0.71}{s} + 1.24\, p_f}$$

$$p(t) = \frac{T \cdot p_f^2}{M \cdot p_i + D \cdot p_f + T \cdot p_f^2} = \frac{1}{1 + \frac{M}{T} \cdot \frac{1}{s \cdot p_f} + \frac{D}{T} \cdot \frac{1}{p_f}} = \frac{1}{1 + \frac{1}{p_f}\left(\frac{0.58}{s} + 0\right.}$$

where $p(m)$, $p(d)$, $p(t)$ = probabilities of monozygotic, dizygotic and trizygotic origin. M, D, T = frequencies of monozygotic, dizygotic and trizygotic triplets (5).

If one member of the set is found to be discordant from the other two it may be desirable to decide whether the concordant pair is monozygotic or dizygotic. This question may be answered, as above for twins:

$$p(\mathrm{m}) = \frac{M \cdot p_i}{M \cdot p_i + D \cdot p_f} = \frac{1}{1 + \frac{D}{M} \cdot s} = \frac{1}{1 + 1.4s}.$$

If more than one trait is considered, s becomes, as above:

$$s(\mathrm{a}) \cdot s(\mathrm{b}) \cdot s(\mathrm{c}) \ldots\ldots \cdot s(\mathrm{n})$$

and

$$p_f = p_f(\mathrm{a}) \cdot p_f(\mathrm{b}) \cdot p_f(\mathrm{c}) \ldots\ldots \cdot p_f(\mathrm{n}).$$

V. PROBABILITIES FOR SIMULTANEOUS CONCORDANCE IN A SERIES OF MENDELIAN TRAITS

Numerical values of p_f, s, and s^2, for cases of specified and of unspecified parentage, have been calculated for a number of well-known mendelian traits (Tables 3 and 4). The value of s which is given by simultaneous concordance for any number of these traits can be computed by multiplying together the respective values of s for the individual traits. To obtain the probability that a pair of twins concordant for such a series of traits is of monozygotic origin, this *compound* value of s is inserted in the formula

$$p(\mathrm{M}) = \frac{1}{1 + 2.9s}.$$

If all of the traits listed in Tables 3 and 4 are employed for zygosity-diagnosis, and concordance is found throughout the series (without considering which of the alternative phenotypes is exhibited in each case) the following compound values of s and s^2 are obtained:

	For males	*For females*
$s =$	.0929	.1012
$s^2 =$	.00854	.01024

and the probability that a pair of twins concordant for the whole series of traits is of monozygotic origin is:

	For males	*For females*
$p\ (\mathrm{M}) =$	.789	.773

If, for each pair (or set) of alternative traits, the particular phenotype which is manifested is taken into account, the compound values of s will range between the following minima and maxima:

$$s_{min.} = .00745 \qquad s_{max.} = .144$$
$$s^2_{min.} = .0000553 \qquad s^2_{max.} = .0208$$

and the value obtained for the probability that a pair of twins concordant

TABLE 3

Concordance probabilities

A. Specified parentage

I. Single pair of autosomal genes with complete dominance of one allele

PARENTS	CHILDREN	TPU — TASTE DEFICIENCY			SECRETOR TEST			Rh — FACTOR		
		p_t	s	s^2	p_t	s	s^2	p_t	s	s^2
D — D	D/D	.831	.920	.846	.785	.895	.801	.862	.937	.878
D — D	R/R	.063	.250	.063	.063	.250	.063	.063	.250	.063
D — R	D/D	.699	.875	.766	.565	.796	.634	.782	.915	.837
D — R	R/R	.250	.500	.250	.250	.500	.250	.250	.500	.250
R — R	R/R	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

II. Single pair of autosomal Genes: Heterozygote identifiable. (M-N reaction)

PARENTS	CHILDREN									
	M/M			MN/MN			N/N		
	p_t	s	s^2	p_t	s	s^2	p_t	s	s^2
M — M	1.0	1.0	1.0	..	..	..	..	..	..
M — MN	.250	.500	.250	.250	.500	.250	..	..	..
M — N	..	..	..	1.0	1.0	1.0	..	..	..
MN — MN	.063	.250	.063	.250	.500	.250	.063	.250	.063
MN — N	..	..	..	.250	.500	.250	.250	.500	.250
N — N	..	..	..	..	..	..	1	1	1

TABLE 3 *(Continued)*

Concordance probabilities

A. Specified parentage

III. Blood groups

PARENTS	CHILDREN											
	A/A			B/B			AB/AB			O/O		
	p_t	s	s^2	p_t	s	s^2	p_t	s	s^2	p_t	s	s^2
A — A	.689	.836	.699	..	..	..	..	..	..	.063	.250	.063
A — B	.093	.320	.102	.072	.275	.076	.123	.379	.144	.063	.250	.063
A — AB	.250	.500	.250	.063	.250	.063	.093	.320	.102	..	..	..
A — O	.371	.639	.408	..	..	..	..	..	..	.250	.500	.250
B — B	..	..	..	.607	.782	.612	..	..	..	.063	.250	.063
B — AB	.063	.250	.063	.250	.500	.250	.072	.275	.076	..	..	..
B — O	..	..	..	.289	.549	.301	..	..	..	.250	.500	.250
AB — AB	.063	.250	.063	.063	.250	.063	.250	.500	.250	..	..	..
AB — O	.250	.500	.250	.250	.500	.250	..	..	..	..	..	..
O — O	..	..	..	..	..	..	..	..	..	1.0	1.0	1.0

IV. Color blindness

PARENT	SONS						DAUGHTERS					
	CB (color blind)			N (normal)			CB			N		
FATHER MOTHER	p_t	s	s^2	p_t	s	s^2	p_t	s	s^2	p_t	s	s^2
N — N	.250	.500	.250	.863	.950	.903	..	..	..	1.0	1.0	1.0
CB — N	.250	.500	.250	.863	.950	.903	.250	.500	.250	.863	.950	.903
N — CB	1.0	1.0	1.0	..	..	..	..	..	..	1.0	1.0	1.0
CB — CB	1.0	1.0	1.0	..	..	..	1.0	1.0	1.0	..	..	..

Symbols as in text:

p_t = probability that both members of a random set of fraternal twins will show a given trait.

$s = \frac{p_t}{p_i}$

p_i = probability that both members of a random set of identical twins will show a given trait.

TABLE 4

Concordance probabilities

B. Unspecified parentage

TRAIT	ALLELES	GENE FREQUENCY		p_I	s	s^2	ALLELE NOT SPECIFIED s	ALLELE NOT SPECIFIED s^2
Sex	Male (YX)	Y = .5		.250	.500	.250	.500	.250
	Female (XX)			.250	.500	.250		
Secretion of agglutinogens	Secretor (SS + Ss)	S = .46	(3)†	.590	.832	.693	.763	.582
	Non-secretor (ss)	s = .54		.173	.593	.352		
TPU — Taste deficiency	Taster (TT + Tt)	T = .55	(10)	.701	.880	.774	.807	.651
	Non-taster (tt)	t = .45		.106	.526	.276		
Rh — factor	Rh + (RHRH + RHrh)	RH = .61	(9)	.769	.907	.823	.843	.711
	Rh — (rhrh)	rh = .39		.074	.483	.233		
M-N reaction	M (MM)	M = .55	(3)	.182	.601	.361	.597	.356
	MN (MN)			.309	.624	.389		
	N (NN)	N = .45		.106	.526	276		
Blood groups	A (AA + Aa)	A = .259	(4)	.281	.679	.461	.659	.434
	B (BB + Bb)	B = .073		.051	.489	.240		
	AB (AB)			.013	.342	.117		
	O (OO)	O = .670		.314	.699	.489		
Color vision	Color-blind male (Yx)	x = .1*	(10)	.055	.550	.303	.910	.828
	Normal male (YX)	X = .9		.855	.950	.903		
	Color-blind female (xx)	...		.006**	.550	.303	.992	.984
	Normal female (XX + Xx)	...		.986	.996	.991		

* As tested by the Ishihara test, i. e. including the anomalous trichromats.

** This figure is actually too low since a few heterozygous females appear color-blind on the Ishihara test.

† Figures in parentheses refer to bibliography.

throughout is monozygotic will lie between $p(\mathrm{M})_{min.} = .705$ and $p(\mathrm{M})_{max.} = .979$.

In the majority of cases it makes little difference whether one uses the formulas for specified phenotypes (for instance $s(\mathrm{R})$, $s(\mathrm{D})$, or whether one considers concordance irrespective of which allele is found (s(R or D), see Table 1). The compound value of s will be approxi-

mately the same if a test is made for a sufficiently large number of traits.

As mentioned above, knowledge of the parents and/or other relatives is desirable. Examination of both twins and their parents adds substantially to the information. The resulting compound values of s and $p(M)$, in the case most favorable for distinguishing between monozygosity and dizygosity, will be

$$s_{min.} = \frac{1}{2^{15}} \; ; \; s^2_{min.} = \frac{1}{2^{30}} \; ; \; p(M)_{max.} = .9993.$$

VI. DISCUSSION

The principle of the methods presented here is not new. Rife (6) has used a similar approach to zygosity diagnosis but he failed to exploit the possibility of applying gene frequencies to cases of unspecified parentage. Essen-Möller (7, 8) did not use information provided by the relatives but his method for cases of unspecified parentage is essentially the same as that described here though both his formulas and their derivation are somewhat different. Since Essen-Möllers publications are not easily available to most readers, it seemed worth while to re-state the whole problem and to present a solution which is more conveniently applied to a random set of twins or triplets.

The numerical values for the probability of monozygosity based on simultaneous concordance in a number of mendelian traits, as given in the preceding section, show that under favorable conditions examination for such traits can help greatly to establish correct zygosity-diagnosis. But they also show that with unspecified parentage concordance for sex and the six other traits is rarely adequate to establish monozygosity beyond reasonable doubt. Further evidence may sometimes be found by careful search for some rare dominant or recessive trait. But usually additional tests will be necessary. The number of common traits for which the mode of inheritance and gene frequencies are known is still limited. But it is not necessary to limit oneself to such traits: s may be determined for any genetic variable whether the mode of inheritance is known or not.

The ratio of concordant fraternal to all fraternal twins gives $p_f(D)$ or $p_f(R)$, and the ratio of concordant identical to all identical twins, $p_i(D)$ or $p_i(R)$. Continuous variables may be converted to discontinuous ones. In this way dermatoglyphic variables can be utilized

(6, 8). Concordance-discordance ratios for various traits may be found in the literature. But certain precautions must be observed in order to avoid errors:

1. Concordance-discordance ratio should be derived from random samples of twins. Data derived from suitably biased samples can be corrected for the fact that they contain an excess of fraternal twins[1] but it is not always evident how a given sample is biased.

2. Traits which are correlated, linked or which are influenced by environment are of limited usefulness.

3. All statistical frequencies must be derived from representative samples. The frequencies of the common genes given above apply to the white population of the United States (19). Some of these genes have entirely different frequencies among the Negro and the American Indian. Erroneous frequencies of common genes can produce considerable errors in the formulas used here. On the other hand, the exact frequencies of rare genes are of minor importance in zygosity studies. Similarly, the value $\frac{F}{I} = 2.9$ is valid for the white population of the U. S., a fair approximation for most European countries and the American Negro but far too large for China and Japan (11). The frequencies of anthropological traits in a group of Swedish twins used by Essen-Möller (8) have very limited value for studies done elsewhere.

It is evident that minor errors are hard to avoid. A sufficiently large number of tests will make such errors irrelevant and elaborate mathematical corrections unnecessary.

VII. SUMMARY AND CONCLUSIONS

Discordance in strictly hereditary traits proves unequivocally polyzygosity. Concordance in such traits does not establish monozygosity

[1] If a survey of amaurotic idiocy were made one would find a number of twin pairs in which one or both members show the disease. One would find $s = 1/7$ instead of the expected value 1/4 because the sample contains only 1/4 of the identical twins born to heterozygous parents but 7/16 of the fraternal twins. The error may be corrected by writing:

$$p(\mathrm{M}) = \frac{1}{1 + \frac{7}{4}\frac{F}{I} \cdot s} = \frac{1}{1 + \frac{F'}{I'} \cdot s}$$

where F' and I' are the actual frequencies of fraternal and identical twins found in the biased sample.

with equal certainty. But it is possible to estimate the probabilities of mono- or polyzygotic origin for concordant twins and triplets of specified and unspecified parentage. The derivation of these concordance probabilities is described. The methods presented here have certain advantages over those found in the literature.

I wish to thank Dr. Paul R. David, Dept. of Biostatistics, School of Hygiene and Public Health, The Johns Hopkins University, for his careful scrutiny of an earlier draft of this paper. His critical analysis has helped me to avoid certain errors and has greatly contributed to clarifying some of the derivations.

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THE SKELETAL AND DENTAL DEVELOPMENT AND VARIABILITY OF THE GORILLA*

BY FRANCIS E. RANDALL
Departments of Anthropology and of Biology, Harvard University

INTRODUCTION

THE skeletal and dental development and variability of man have been studied extensively and in very considerable detail, particularly during the last few decades. For the thorough evaluation of this newly acquired information we have lacked until recently an adequate scale of comparative data appertaining to man's nearest animal relations, the man-like apes. The differences between man and the higher apes are chiefly of a quantitative nature and hence can be discovered and described only by statistical methods, applied to observations on large series of specimens, including all stages of development. Such series are readily available in the study of man, but have rarely been used for other primatological investigations. Within the last few years there have appeared some detailed reports, based upon extensive material, on the development and variability of the skeleton and the teeth of two of the anthropoid apes, the orang-utan and the chimpanzee (Schultz, 1940a and 1941). No complete investigation of this sort has been available for the third great ape, the gorilla. With the present paper it is intended to fill this gap in our knowledge, so that it will become possible to compare man with all other recent higher primates in regard to the postnatal age changes in the skeleton and teeth and the amount and kind of variations in these conditions. This report is primarily a record of new data, collected on as extensive a series of specimens as has been possible to obtain. No attempt has here been made to compare the new findings with the corresponding

* Revision of part of a thesis submitted for the degree of Doctor of Philosophy in Biology, Harvard University, 1942.

information that has been published on the other great apes and on man.

This investigation was undertaken at the suggestion of Dr. Adolph H. Schultz, who instructed the writer in the technique employed and outlined many of the problems to be dealt with in this study. Thus it became reasonably certain that the data recorded here can be compared directly with those already published by Schultz for the orang-utan and the chimpanzee.

The gorilla material studied by the writer had been generously placed at his disposal in the following collections: Western Reserve University, Cleveland, Ohio, provided the great majority, due to the long range collection policies of the late Dr. T. Wingate Todd; the American Museum of Natural History in New York; the United States National Museum; the Museum of Comparative Zoology; the Museum of the Philadelphia Academy of Sciences; the Peabody Museum; the private collections of Dr. Schultz; and the Army Medical Museum. One privately owned skull was loaned by H. J. Coolidge, Jr., of the Museum of Comparative Zoology.

Sources of material

	Sub-I*	I*	II*	III*	IV*	V*	VI*	Total
Western Reserve University	..	8	21	27	33	71	165	325
American Mus. of Nat. Hist.	3	4	5	1	3	6	26	48
United States Nat. Museum	..	..	1	..	3	9	34	47
Mus. of Comp. Zoology	1	..	..	2	1	5	17	26
Phila. Acad. Sci. Museum	..	2	..	..	1	5	3	11
Peabody Museum	..	1	..	1	..	1	4	7
A. H. Schultz, Lab. Phys. Anth.	..	1	2	..	..	..	..	3
Army Medical Museum	..	..	..	..	..	1	1	2
H. J. Coolidge, Jr.	..	..	..	..	..	1	..	1
Dental age totals	4	16	29	31	41	99	250	470

* These numerals represent dental ages as described later.

The author wishes to express his sincere thanks for having been permitted to examine this material, particularly to Prof. N. L. Hoerr of the Department of Anatomy of Western Reserve University; Mr. H. C. Raven and Dr. Harry Shapiro of the American Museum of Natural History; Mr. G. S. Miller, Jr., of the United States National Museum; Dr. G. M. Allen of the Museum of Comparative Zoology,

Harvard University; Mr. Cadwalader of the Museum of the Philadelphia Academy of Sciences; Dr. E. A. Hooton of the Peabody Museum, Colonel Ash of the Army Medical Museum, and Dr. Schultz and Mr. Coolidge.

The writer is especially grateful to Dr. A. H. Schultz and to Dr. E. A. Hooton for their manifold help and criticism throughout the period of this study.

The exact origin of most of the skeletons and skulls is doubtful. The Western Reserve collection is almost entirely French West Cameroons. So far as possible, the stated origin determined the use of the material. All skeletons used were stated to be *Gorilla gorilla*. Further discussion of the implications of the origins will be made in the section on cranial variability.

SKULL

A total of 456 skulls was studied. These may be divided as follows:

Dental age	*Male*	*Unsexed*	*Female*
Sub-I	..	4	..
I	..	16	..
II	22	..	7
III	19	..	12
IV	29	..	11
V	62	..	31
VI	151	..	92
Totals	283	20	153

The problem of ageing this material requires certain comments for clarification. The Krogman (1931) scale was used for this study because it offered criteria for the maximum number of growth stages without resorting to individual assessments. Schultz (1940a) uses four stages in his studies on the anthropoids. The two systems are rather easily correlated, as shown in the table below. A list of metric data based upon the Schultz chronology is given in Appendix A.

It is the author's opinion that the Schultz classification is too broad in the last two stages, as will be shown later. The Krogman classification is more detailed but suffers under strict interpretation. Stage III is especially difficult because the premolars and the incisors do not

Krogman	*Dental formula*	*Schultz*
Stage I	$\frac{\text{il-2}\ \text{c}\ \text{ml-2}}{\text{il-2}\ \text{c}\ \text{ml-2}}$	Infants up to complete deciduous dentition
Stage II	$\frac{\text{il-2}\ \text{c}\ \text{ml-2}\ \text{M1}}{\text{il-2}\ \text{c}\ \text{ml-2}\ \text{M1}}$	Juvenile I. Complete deciduous dentition and 1 to 4 first permanent molars. This stage is II in the Krogman usage
Stage III	$\frac{\text{Il-2}\ \text{c}\ \text{Pml-2}\ \text{M1}\ \text{M2 erupting}}{\text{Il-2}\ \text{c}\ \text{Pml-2}\ \text{M1}\ \text{M2 erupting}}$	Juvenile II. M1 and 1-24 additional permanent teeth, i. e. to completion of permanent dentition, but without full occlusion of M3
Stage IV	$\frac{\text{Il-2}\ \text{C erupting}\ \text{Pml-2}\ \text{Ml-2}\ \text{M3 erupting}}{\text{Il-2}\ \text{C erupting}\ \text{Pml-2}\ \text{Ml-2}\ \text{M3 erupting}}$	
Stage V	$\frac{\text{Il-2}\ \text{C new}\ \text{Pml-2}\ \text{Ml-2-3 new}}{\text{Il-2}\ \text{C new}\ \text{Pml-2}\ \text{Ml-2-3 new}}$	Adults, completion and attrition of permanent dentition
Stage VI	All permanent teeth are worn	

always erupt so abruptly as the notation indicates. Therefore, this eruption period usually belongs to Stages II and III but occasionally may fall into IV. In the final analysis, the condition of molar eruption is the determining factor. Stage V is also somewhat vague in the same regard. The male canines quite often follow M3 in reaching their final growth, so actually follow the "all teeth new" condition. Because of this last difficulty, a further criterion was introduced. It was found that the period following the final eruption of M3 and the complete closure of the basilar suture permitted the variation in time required for the final position of the canines. Thus, all skulls with M3 in place but without the basilar suture closed were classified as Stage V. Upon closure of the suture, the skulls were classified as Stage VI, regardless of the degree of dental attrition.

Further compromises are necessary in deciding the position of any given skull on this scale of classification. When is an erupting molar to be considered as erupted? This is especially difficult on the skull. In studies on the living, the usual procedure is to consider the appearance of the tooth above the gum as the line of demarcation. The technique used in connection with skulls is as follows: The mandible is placed in position and it is observed whether or no occlusion exists. If the upper and lower molars were still far apart, they were recorded

as unerupted and if they approached rather closely, they were considered erupted.

The problem of sexing young skulls is especially difficult. Stages IV, V, and VI are easy, because the canines and the crests are clearly defined. But I, II, and III do not show these characteristics to gross inspection, and the other metric and morphological traits are either so close together in both sexes or the ranges overlap so greatly that there is no method by which accurate assessment can be made by mere gross observation. It was for this reason that X-rays were attempted. Through the kindness of Dr. Broadbent, Director of the Bolton Inquiry, this X-ray study was expanded to include norma-lateralis, norma-frontalis, and norma-basilaris views of all the Western Reserve University skulls of the lower three dental ages and of representative skulls of the upper three. Stage III may be sexed by means of X-rays with practical certainty. Suffice it to say here that the canine lying in its crypt is just as definitive as it is after its eruption. Stage II is not so easy, but the canine buds themselves are advanced far enough that the author believes that the sexing based upon this criterion in the second stage is sufficiently accurate to produce greater dependability than was possible without the aid of X-rays. Dental Age I appears to produce no criteria sufficiently dependable to permit even tentative sexing, hence was considered as unsexed material.

Analysis

Metric

The techniques for the individual traits studied will be discussed under their separate headings. The discussion will be based upon the mean growth rates and the statistical data will be listed at the end of this section.

Eighteen metric traits were tested according to techniques described by Schultz (1933a), and three indices were calculated from some of them.

Cranial capacity

Technique. Capacities were taken according to the techniques used by Schultz (1941) in his primate studies. Rape seed was used as the semi-fluid medium. Cotton was used to stopper the foramina. The

seed was introduced, and the skull was agitated for some time to insure an even penetration into all the spaces. It was then poured, by means of the Hrdlička funnel, into a 1000-cc. graduate and the top surface leveled by vibration. The volume was read directly. This technique was checked against the standard Hrdlička method and the differences obtained were found to be negligible.

Comment. As would be expected, the maximum increase in cranial volume occurs at an early age. The percentage increases may be tabulated in the terms of the final reached.

	Male	*Female*
	Per cent of Stage VI	Per cent of Stage VI
Stage I*	78.9	94.3
II**	88.7	90.0
III	92.0	101.5
IV	95.4	99.7
V	98.5	102.5
VI	100.0	100.0

* Unsexed.
** Tentatively sexed.

These percentages indicate that there is considerable sexual disparity in the attainment of the final adult capacity.

Stage I also indicates that there is already some difference in the two sexes. The fact that the mean for the unsexed skulls exceeds the female Stage II shows that the female is somewhat smaller than the male. As shown by the percentage table, the female reaches her final capacity at about Stage III, but the male does not stop here. It shows some increase at every stage. The final increase, between V and VI, is not statistically significant, but the increases between IV and V and IV and VI are, so it must be concluded that there is still an increase going on. Thus, it appears that the female reaches her final cranial capacity at approximately Stage III, and the male at Stage V. A similar great sexual diversity will be encountered in nearly all the traits studied.

Orbital capacity

Technique. The orbital foramina were plugged with cotton which was pressed down to follow the contours of the orbital walls as nearly

as possible. Rape seed was poured in and leveled off with the orbital margins. The seed was then poured into a 100-cc. graduate. The top surface was leveled by vibration and the volume read. This technique also follows that used by Schultz (1940b).

Comment. In the orbital capacity, we find the first trait in which the male and female are fairly similar in the early stages, as shown by the following table in which orbit capacity is expressed in percentage of its final size in adults:

	Male	*Female*
	Per cent of Stage VI	Per cent of Stage VI
Stage I*	34.9	46.0
II**	55.7	62.3
III	64.6	78.8
IV	78.9	92.2
V	94.2	94.7
VI	100.0	100.0

* Unsexed.
** Tentatively sexed.

It will be noted that Stages I, II, and III are close together, but at Stage IV a divergence begins which continues through the final stages. In this trait we also find statistically significant growth between Stages V and VI in both sexes, with the male again showing somewhat more exuberance. We encounter in this trait a factor which is manifested many times throughout the male growth. This is the marked pause in the rate which occurs between Stages II and III. It is possible that this apparent retardation may be due to the relatively small numbers—22 in II and 19 in III—but, since the same slackening occurs in other traits, we must assume that it is really characteristic of this growth stage. It is possible that this period represents a condition analogous to that shown in human growth and known as the preadolescent lag. The situation is comparable, because this period permits the female to exceed temporarily or to approach the male. The dental stage pattern is also somewhat comparable.

Maximum length

Technique. The maximum length is the distance from glabella to opisthocranion or inion, which coincide in the gorilla, due to the fact

that the occipital crest, or the "nuchal line," is so expanded that its inion point is also the opisthocranion.

Comment. Here, for the first time, we encounter the confusing problem of the crests in gorilla. These crests have long been "bones of contention" in the consideration of gorilla skulls, both metrically and morphologically, due to the fact that their variabilities have never been sufficiently studied. Should or should not these crests be included in cranial dimensions? The problem of the crests will be fully considered under the discussion on variabilities. Suffice it to say here that the author believes the crests should be included in the "maximum" length dimensions.

The percentage increases indicate somewhat the involvement of the crests, especially in considering the sexual divergence in growth itself.

	Male	*Female*
	Per cent of Stage VI	Per cent of Stage VI
Stage I*	65.6	82.0
II**	73.8	85.3
III	78.3	94.0
IV	85.0	97.4
V	96.0	99.5
VI	100.0	100.0

* Unsexed.
** Tentatively sexed.

These figures indicate that the male proceeds at a moderate rate up to Stage IV and the female maintains a constant rate throughout her entire growth period.

Here again the two sexes remain rather similar in some respects throughout the lower three stages, with some degree of similiarity persisting even into Stage IV. But after Stage IV, the male crests enter the picture and increase the rate considerably, with a statistically significant growth occuring even in the interval between V and VI. No significant change occurs in the female after Stage IV. No "pre-adolescent" pause occurs in this trait.

Cranial length

Technique. Cranial length represents the distance from glabella to a point as near the mid-line as possible determined by the point of

maximum inflection in the contour from the cranial vault to the occipital crest. The determination of this point is not too definite but approximates the termination of the canial vault of the skull.

Comment. In spite of the fact that the supra-orbital ridges obscure to some extent the basic structure of the cranial vault, this dimension shows a marked correlation with the cranial capacity.

	Male	*Female*
	Per cent of Stage VI	Per cent of Stage VI
Stage I*	78.7	88.2
II**	87.8	91.5
III	90.0	97.3
IV	92.9	97.5
V	98.8	98.9
VI	100.0	100.0

* Unsexed.
** Tentatively sexed.

The male continues its progress up to Stage V, with a non-significant increase in the last period. The female completes her increase by IV at the latest. The male again lags during the II-III period.

Inion-prosthion

Technique. This distance is taken in the usual manner. It represents the maximum dimension of the skull exclusive of the teeth.

Comment. The inion-prosthion distance shows the steepest rate of any of the dimensions because it incorporates both the cranial and the facial increases.

	Male	*Female*
	Per cent of Stage VI	Per cent of Stage VI
Stage I*	52.6	68.3
II**	65.8	77.4
III	74.0	90.3
IV	83.5	95.5
V	94.5	99.2
VI	100.0	100.0

* Unsexed.
** Tentatively sexed.

The male continues throughout the entire growth period while the female reaches her limit by Stage V. The period II to III again shows the lag in the male accompanied by a spurt in the female. The spurt of the female may be only an apparent one due to small numbers, with only 7 in II, and 12 in III.

We notice here again that there is no marked difference in the male and female dimensions up through Stage III, with a slight increase at IV, and then a tremendous divergence at V and VI. But this time we must include, besides the crests, the greater increase in the facial dimensions. It is noteworthy to observe throughout most of the traits that there is no great difference in the lower three dental ages, with even practically the same dimensions at Stage III. It is only after Stage III that the excessive "masculinity" of the male enters the picture. The solution of the problem of the correlation of sexual maturity with this divergence would be one of great interest.

It will be noticed in the drawings that the basic occipital crest appears in the skulls of both sexes, even at Stage I, and expands correspondingly in the next two stages. It is not until Stage IV that the male crests begin to surpass the females.

Basion-prosthion

Technique. The basion-prosthion distance is also taken in the usual manner.

Comment. This dimension gives us the first insight into the growth of the lower aspect of the face due to the involvement of the dental eruption.

	Male	*Female*
	Per cent of Stage VI	Per cent of Stage VI
Stage I*	46.2	58.5
II**	64.2	72.3
III	74.7	88.6
IV	87.2	95.8
V	96.6	101.0
VI	100.0	100.0

* Unsexed.
** Tentatively sexed.

Even here we encounter no marked divergence between male and female until Stage IV is reached.

Since Stage IV sees the eruption of M3, we must conclude that the final effect of the masculine dentition is reached with that tooth and not to any great extent before. This fact is supported by the study of the palate length itself. The usual retardation in the period between II and III is observed in the male, accompanied by some increase in the female in the same period.

Probably the most interesting fact in this particular trait is that there is statistically significant growth in the dimension following the full eruption of M3, that is, in the period between V and VI. This is apparently due to a filling-out process in the alveolar margin back of M3 and not to any increase at the front of the arcade. The presence of M4's does not affect the dimension.

Basion-nasion

Technique. Nasion represents the most difficult point on the gorilla skull. This is because of two conditions: one, the nasal bones quite often extend as far up as glabella, making nasion coincide with that point; two, the naso-frontal suture is obliterated by Stage V, so that it is impossible to find the site of the original juncture. For this reason, an arbitration had to be used. The most constant trait of the sutures in the region is that of the juncture between the maxillae and the frontal bones, lateral to the nasals. These sutures are formed in an arch shape so that a tangent may be drawn. The arches persist as grooves into adult life. Thus, the tangent to them is easily determined. This line then crosses the nasal ridge at approximately the lowest point of its curvature as viewed in the norma-lateralis. This point is termed "nasion" and represents a rather constant assessment. Basion-nasion is the best expression for the length of the base of the skull.

Comment. We have in this dimension one of the clearest signs for the radical departure of the male from the female in the period from III to IV.

	Male	*Female*
	Per cent of Stage VI	Per cent of Stage VI
Stage I*	59.0	70.4
II**	72.7	78.0
III	79.2	91.5
IV	88.9	96.8
V	97.9	100.3
VI	100.0	100.0

* Unsexed.

** Tentatively sexed.

There occurs the usual compensating lag in the male and increase in the female in the period between Stages II and III, with an almost equal dimension in Stage III in both sexes. There is statistical significance in the growth between V and VI.

Maximum breadth

Technique. This is the greatest width of the cranium between the sutures of the parietal and temporal bones. It represents a close approach to the cranial width, to accompany the cranial length dimension already described and the cranial height to be described later.

Comment. The maximum breadth at the squamous suture shows some of the effects of growth processes better than most of the other traits.

	Male	*Female*
	Per cent of Stage VI	Per cent of Stage VI
Stage I*	99.0	102.0
II**	101.6	101.7
III	101.2	100.2
IV	102.2	99.5
V	99.5	100.2
VI	100.0	100.0

* Unsexed.
** Tentatively sexed.

Although the female shows no significant changes throughout the growth period, the male does show a statistically significant decrease from Stage IV to Stages V and VI. The reasons for this situation are probably twofold: one, the cranial vault is increasing in height, which condition may be accompanied by a decrease in the breadth; two, the more probable cause, the temporal bone is passing through a great increase in growth during this period which probably is accompanied by a splaying-out of the bone in the suture itself, with an accompanying decrease in the distance between the edges of the bone. Thus, the actual endocranial diameter may not change significantly even though an apparent change is occuring in the outside diameter.

Total maximum breadth

Technique. This diameter is the maximum distance between the

mastoid processes and lies slightly above the external auditory meati. In short, it is the maximum cranial breadth.

Comment. The significant growth in the dimension of the male between Stages IV and V, V and VI, shows how greatly this dimension is involved in the exuberance of the males. The female reaches her limits by V, for all practical purposes by IV. Otherwise the growth rates are comparatively smooth.

	Male	*Female*
	Per cent of Stage VI	Per cent of Stage VI
Stage I*	63.0	77.1
II**	74.0	84.7
III	80.8	93.2
IV	88.8	97.4
V	96.0	100.6
VI	100.0	100.0

* Unsexed.
** Tentatively sexed.

Postorbital breadth

Technique. This dimension is, in reality, the minimum frontal breadth, being taken at the point of maximum constriction of the cranium posterior to the supra-orbital crests.

Comment. We have here the best indication of the fluidity of the relationship between the relative growths of the cranium and the facial skeleton.

	Male	*Female*
	Per cent of Stage VI	Per cent of Stage VI
Stage I*	96.9	100.1
II**	103.2	100.1
III	104.0	102.6
IV	101.2	102.2
V	101.5	101.3
VI	100.0	100.0

* Unsexed.
** Tentatively sexed.

The decrease from Stage III to Stage VI is real and significant.

It seems tha flow of the bony structure accompanies the increase in breadth in the cranial region and in the facial region. We have, also, the increase in the cranial height and the marked increase in the basion-nasion dimension to aid this movement. Thus, for the increases mentioned above, we have a concomitant decrease in the postorbital breadth which serves as an excellent illustration of actual decrease in a dimension while progressive growth processes are going on in adjacent regions.

Biorbital breadth

Technique. This dimension is the maximum horizontal distance between the external margins of the orbital rims.

Comment. This dimension falls into the same category as do the cristal dimensions and the maximum breadth dimensions. It indicates clearly the sexual divergence following Stage III.

	Male	*Female*
	Per cent of Stage VI	Per cent of Stage VI
Stage I*	53.2	65.2
II**	67.9	77.0
III	74.0	88.7
IV	85.5	95.8
V	96.0	99.1
VI	100.0	100.0

* Unsexed.
** Tentatively sexed.

Here, again, we find the retardation in the male between Stage II and Stage III, with an increase in the female and almost identical dimensions at Stage III. We also find statistically significant growth following Stage V in the male.

Interorbital breadth

Technique. This is the minimun breadth between the medial walls of the orbits, wherever found. It is not defind by any points but rather by the arbitration of the observer. The measurement must not be taken back in the orbit itself, because the medial walls diverge considerably; neither should it be taken too far forward because the medial margins are quite rounded.

Comment. Almost the same comment will serve to describe the growth pattern of this dimension as was given for biorbital breadth. The period between Stage II and Stage III shows the lag in the male and the spurt in the female, but here we do not have any statistical significance in the growth following Stage V.

	Male	*Female*
	Per cent of Stage VI	Per cent of Stage VI
Stage I*	35.6	48.8
II**	51.9	57.4
III	62.6	80.0
IV	78.3	96.7
V	95.1	99.2
VI	100.0	100.0

* Unsexed.
** Tentatively sexed.

Bizygomatic breadth

Technique. Maximum external breadth between the zygomatic arches, wherever found.

Comment. The male lag and the female spurt are again observed between Stage II and Stage III, and there is statistically significant growth in both sexes between V and VI. Otherwise, the pattern is as usual.

	Male	*Female*
	Per cent of Stage VI	Per cent of Stage VI
Stage I*	53.3	65.0
II**	67.5	76.1
III	75.6	90.5
IV	85.6	94.0
V	96.5	98.3
VI	100.0	100.0

* Unsexed.
** Tentatively sexed.

Total skull height

Technique. Total skull height is the distance from basion to the top of the skull at a point lying vertical to basion in the Frankfort Horizontal, including the sagittal crest when present.

Comment. This distance shows that there is close similarity in the two sexes until Stage IV, at which time the sagittal crest begins a rapid growth in the male.

	Male	*Female*
	Per cent of Stage VI	Per cent of Stage VI
Stage I*	69.7	91.8
II**	75.5	92.7
III	77.2	100.0
IV	80.5	100.0
V	93.4	102.0
VI	100.0	100.0

* Unsexed.
** Tentatively sexed.

Cranial height

Technique. Cranial height is the third cranial vault dimension. It has the same difficulty as has the cranial length, due to the sagittal crest. The dimension was taken from basion to the point of maximum inflection between the vault contour and that of the sagittal crest, vertical to the Frankfort Horizontal.

Comment. In this trait we have the greatest resemblance between the two sexes.

	Male	*Female*
	Per cent of Stage VI	Per cent of Stage VI
Stage I*	86.5	91.5
II**	93.6	92.5
III	95.0	99.8
IV	96.9	99.8
V	99.8	101.9
VI	100.0	100.0

* Unsexed.
** Tentatively sexed.

No significant growth occurs following Stage III in the female and following Stage V in the male.

Face height

Technique. This is the distance from nasion, as previously defined, to prosthion. Occasionally, the adult gorilla skull fails to have the

suture completely closed between the premaxillary bones at the region of prosthion. If this was the case, the distance was taken to a point midway between the alveolar tips and on the line tangent to them. Younger skulls commonly have this condition.

Comment. It is in the height of the face that we find one of the most consistently divergent dimensions in the two sexes.

	Male	*Female*
	Per cent of Stage VI	Per cent of Stage VI
Stage I*	52.5	63.4
II**	69.3	78.5
III	85.8	88.8
IV	89.5	95.9
V	98.3	100.0
VI	100.0	100.0

* Unsexed.
** Tentatively sexed.

Some retardation occurs in the II-III interval in the male. The author believes this factor to be important in the consideration of the type of occlusion of the teeth. This point will be discussed further under the dentition.

Palate length

Technique. This distance was taken by placing the sliding calipers parallel to the long axis of the palate and touching the fixed end to the posterior alveolar margin in the back and the movable arm to the prosthion in front. Thus, it is the longitudinal distance between the posterior limits of the alveolar arch and the anterior tangent of that arch.

Comment. The palate length follows the same growth rate as does the facial height.

	Male	*Female*
	Per cent of Stage VI	Per cent of Stage VI
Stage I*	47.1	58.4
II**	63.7	78.9
III	75.5	86.3
IV	88.1	93.7
V	96.5	99.0
VI	100.0	100.0

* Unsexed.
** Tentatively sexed.

Palate breadth

Technique. This dimension is the maximum external breadth of the palate wherever found.

Comment. A moderate growth rate is recorded in both sexes for this diameter. The region in which the maximum breadth is found will be listed by consecutive stages to indicate the gradual progress from the broad U of the youthful skulls up to the excessively elongated U of the adults.

Stage I shows the widest breadth at m2 in 75 per cent of the cases recorded, and 25 per cent have the widest breadth at ml. Thus, there appears to be somewhat of a constriction of the posterior region of the alveolar arch.

At Stage II, all the males have the broadest portion of the palate in the M1 region. The female skulls exhibit this condition as well.

The males, at Stage III, have 78 per cent of the cases at M1, 16 per cent at M2, and 6 per cent at P1. All the females have their widest dimensions at M1.

Stage IV sees the beginning of the swelling anteriorly due to the erupting canine. For this reason, the widest region begins to progress anteriorly again. Of the males, 31 per cent are still at M2, but now 14 per cent are at M1, 24 per cent at P1, and 31 per cent are already at C. The females have 45 per cent at M2, 36 per cent at M1, 9 per cent at P2, and 9 per cent at P1. Thus, the females lag behind the males to a great degree at this stage.

Stage V sees the progression well along. In the males, 7 per cent are still at M2, 14 per cent are at M1, 28 per cent are at P1, and 51 per cent are at C. Our familiar sex diversity continues here. The females have 17 per cent at M2, 59 per cent at M1, and 24 per cent at P1.

By stage VI, 8 per cent of the males remain at M2, 6 per cent at M1, 28 per cent at P1, and 58 per cent are at C. Thus we have a rather high degree of variability in the location of this dimension. Two Stage-V skulls had four molars, and twelve of the Stage-VI males contained these supernumerary teeth in some degree.

M4 in Stage-V skulls

Upper right only	1
Lower left only	1
	2

M4 in Stage-VI skulls

Upper left only	1
Upper right only	5
Upper bilateral	4
Lower bilateral	1
All four	1
	12

None of the female skulls showed fourth molars. The female skulls have greatest breadths in 14 per cent at M2, 64 per cent at M1, 2 per cent at P2, 17 per cent at P1, and 2 per cent at C. Thus, our adult male skull has the greatest proportion of its palate maximum widths falling at C, whereas the adult female has its greatest proportion at M1.

	Male	*Female*
	Per cent of Stage VI	Per cent of Stage VI
Stage I*	62.6	70.1
II**	77.5	80.0
III	83.5	90.0
IV	91.2	95.0
V	98.5	97.5
VI	100.0	100.0

* Unsexed.
** Tentatively sexed.

Statistically significant growth occurs in both sexes following Stage V.

The progression of the greatest breadth, first from M1-2 posteriorly, then from M1-2 anteriorly, shows that the palate shape first appears, at Stage I, somewhat parabaloid, with a slight constriction at the posterior region of the alveolar rim. Next, it becomes a broad, short U, and finally becomes a long U, with parallel sides.

(*To be continued*)

AN INQUIRY INTO METHODS OF STUDYING THE SEX RATIO AT BIRTH FOR THE UNITED STATES DURING WAR AND POST WAR YEARS*

BY RACHEL M. JENSS
Bureau of the Census

THE normal excess of male over female births, the amount of the excess for subgroups of the population, and variations in the ratio which occur from time to time and which appear to exist under different conditions have been studied by many investigators. For example, there is an extensive literature on changes in the sex ratio at birth which accompany a war. It is only natural that this phenomenon will be studied during the present world conflict. Will the sex ratio at birth for the United States increase as a consequence of the war? This paper is written for the purpose of outlining possible methods for studying the question, and incidentally, to show that the problem is much more difficult than is commonly supposed.

It is assumed frequently that the ratio of male to female births rises during war and post war years. There is a prevalent assumption that the ratio of male to female births increases during and immediately following a war. For example, statements have appeared in the literature, based on tables such as Thompson's,[1] which is reproduced here as Table 1, that the sex ratio at birth increased in certain countries during and immediately following World War I. Thus, it might be deduced

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[1] Warren S. Thompson: Population Problems (McGraw-Hill, 1942), pp. 48-49.

TABLE 1

The ratio of male to female births for fifteen countries, 1911-32

(Adapted from Thompson.)

COUNTRY	1911-13	1915-17	1920-22	1930-32
Australia	104.7	105.5	105.9	105.7
Austria	105.8	105.4	106.6	106.2
Belgium	103.9	104.8	105.5	104.5
Chile	104.9	105.3	104.6	106.4
England	103.9	104.4	105.1	104.8
Finland	106.8	105.9	106.0	105.7
France	104.3	104.7	105.3	104.2
Germany	105.6	106.3	107.2	106.2
Holland	105.0	105.6	105.9	106.5
Hungary	105.4	106.4	107.1	106.1
Italy	105.3	105.5	105.6	104.9
Japan	104.2	104.2	104.3	104.9
New Zealand	105.3	105.4	105.4	106.1
Sweden	105.9	105.6	105.5	105.2
United States	...*	105.7	105.7	105.4

* No figures are available prior to 1915, the year in which the original United States Birth Registration Area was formed.

from this table that the sex ratio at birth for Germany increased during and immediately following the war and then decreased; the ratio for Holland also increased during the war and post war years and continued to increase during the subsequent years shown in Thompson's table.

Conjectures of this kind are not always confirmed by examining all the data that are available. By filling in data missing from Thompson's table, enlarging the period of observation to include the decade prior to the war, and plotting the observations as in Fig. I, it may be seen that although the conjecture for Germany is apparently confirmed,[2] that for Holland is not confirmed.

Although the sex ratio for Germany apparently increased during

[2] Note that the boundaries of Germany changed during the years shown in Table 1 and Fig. I. Variation in the ratio may be associated with these changes.

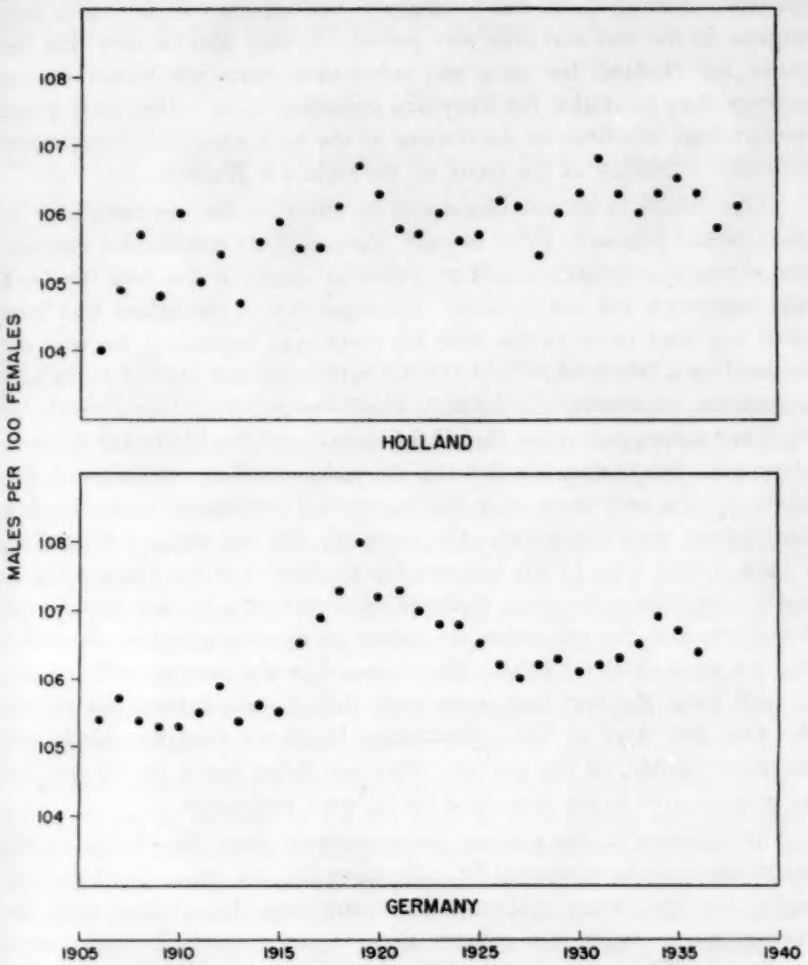

FIG. 1. SEX RATIO AT BIRTH FOR HOLLAND AND GERMANY, 1906 TO 1938
Source: Official statistics of Holland and Germany.

the war and post war years and then decreased, the average ratio for the years following the decrease is higher than the average ratio for the years preceding the increase. There is no apparent explanation for this difference in the average ratios.

The apparent increase in the ratio for Holland during the war and post war years is a continuation of a tendency which existed prior to

the war. Furthermore, this tendency is not apparent in the years subsequent to the war and post war period. It may also be seen that the ratios for Holland for 1924 and subsequent years are higher on the average than the ratios for the years preceding 1924. This shift arises in part from a change in the content of the birth certificate, and causes difficulty in studies of the trend of the ratio for Holland.

The change in the certificate and its effect on the sex ratio may be described as follows: Prior to 1918, the certificate contained a question concerning the infant's condition (alive or dead) at the time his birth was registered, but not at birth. Consequently, if the infant was born alive and died prior to the time his birth was registered, he was not counted as a live birth. In 1918 the certificate was altered to include a question concerning the infant's condition at birth. As a result, in 1918 and subsequent years, the official statistics of live births for Holland show total live births, but for the six years, 1918-23, statistics of live births by sex still show only the number of infants alive at the time their births were registered. Consequently, the sex ratios for 1918-23 (Table 1 and Fig. 1) are comparable to those for the years prior to 1918. Beginning in 1924, statistics of live births by sex show total live births and the sex ratios are larger on the average than the ratios for the years prior to 1924. This increase in the average ratio results in part from the fact that more male than female infants die during the first few days of life. Sex ratios based on total live births are therefore higher, on the average, than sex ratios based on the number of infants alive at the time their births were registered.

This increase in the average ratio resulting from the change in the certificate may be measured by estimating the sex ratios for total live births for the years, 1918-22,[3] and comparing these ratios with the corresponding ratios for infants alive at the time their births were registered. The ratios for total live births may be obtained by adding the number of infants of each sex alive at the time their births were registered and the number of infants of the same sex who had died before their births were registered and dividing the total number of male infants by the total number of female infants. The resulting sex

[3] The ratio for 1923 can not be computed because the number of infants of each sex who had died prior to the time their births were registered is not given in the official statistics for Holland.

ratios and the sex ratios based on the number of infants alive at the time their births were registered are as follows:

Year	Sex ratio	
	All live born infants	*Infants alive at the time their births were registered*
1918	106.3	106.1
1919	106.9	106.7
1920	106.5	106.3
1921	106.0	105.8
1922	106.0	105.7

For each of the five years, the sex ratio for total live births is larger than the sex ratio for infants alive at the time their births were registered.

Many studies in the literature concerned with factors which may be associated with an increase in the sex ratio at birth during war and post war years are also based on inconclusive data. These studies do not control a sufficient number of factors to permit valid deductions being drawn concerning the importance of any one factor. For example, studies concerned with the association of an increase in the sex ratio at birth in war and post war years with the proportion of first births, often fail to control maternal age; conversely, studies concerned with the association of the increase in the ratio and the proportion of births to young mothers often fail to control parity.

To summarize, there is not conclusive evidence in the literature concerning either an increase in the sex ratio at birth during war and post war years, or concerning factors that may be associated with such an increase. It is the purpose of the present inquiry to indicate the kind of factors that need to be controlled and investigated in a study of variations in the sex ratio at birth for the United States as a consequence of the present war.

Differences in sex ratio at birth exist between subgroups of the population of the United States. The sex ratio at birth for Negro infants born in the United States is considerably lower than that for white infants born in the United States. However, the sex ratio for the subgroup of white infants born in the United States to parents who were born in Italy is not much higher than the ratio for Negroes. If an explanation were found for such differences and similarities as these,

it might furnish leads for studying the more difficult problem of the trend of the ratio for the country as a whole.

The sex ratio at birth is dependent on the sex ratio at conception and on the sex ratio among intrauterine deaths. Sex ratio at conception and sex ratio among intrauterine deaths may be associated with certain characteristics of the parents and certain characteristics of the infants. Data that investigators have considered pertinent are listed under the following headings. Some of the characteristics listed (e. g "legitimacy of infant") primarily affect the subclasses of the sex ratio and not its over-all value; some of the characteristics listed are difficult to measure (e. g. "number of previous pregnancy losses"); some are highly correlated with other characteristics that are listed (e. g. "place of delivery" is correlated with "order of birth") and with characteristics that are not listed (e. g. "attendant at delivery" is correlated with prenatal care.)

1. Race and nativity of each parent
2. Residence of mother
3. Occupation of each parent
4. Legitimacy of infant
5. Age of each parent
6. Order of birth
7. Number of previous pregnancy losses
8. Interval between this pregnancy and the one immediately preceding
9. Complications of pregnancy
   - A. Obstetric
   - B. Non-obstetric
10. Place of delivery
11. Attendant at delivery
12. Type of delivery
13. Outcome of pregnancy
    - A. Type of birth
      - i. Single
      - ii. Multiple
    - B. Condition of infant
      - i. Liveborn
        - a. Premature
        - b. Term

ii. Stillborn (including abortions)
   a. Previable product of conception
   b. Viable product of conception
      (i). Death occurring before onset of labor
      (ii). Death occurring after onset of labor

Changes in sex ratio during war and post war years may be studied in various ways. The characteristics to be studied depend on (1) the type of investigation to be made and (2) the possibility of collecting the data. If the analysis is to be based entirely on information contained on birth certificates,[4] the following characteristics may be studied for single live births:[5]

1. Race and nativity of each parent
2. Residence of mother
3. Occupation of each parent
4. Legitimacy of infant
5. Age of each parent
6. Order of birth
7. Number of stillbirths of this mother
8. Place of birth
9. Maturity of infant

[4] Items included in optional section of standard live birth certificate, which has been adopted by 30 of the 48 states and the District of Columbia, may be used in selected areas to evaluate additional characteristics including complications of pregnancy and type of delivery. (The number of states that have adopted the optional section is based on a survey made by the Children's Bureau in the spring of 1942.)

[5] The same analysis can be made for all reported products of conception. Although the ratio for all reported products of conception has theoretical advantages, it has practical limitations. The definition of a stillbirth varies from state to state and from time to time. Early products of conception are reported in some states and not in others. The sex of early products of conception is frequently unknown. Also, the sex of early products of conception is easier to determine for males than for females. Hence, the ratio for total reported products of conception is less accurate than the ratio for live births only.

The study is limited to single births. The study of plural births is complicated by extraneous genetic factors.

An example of the detailed type of analysis which might be made, is presented in the table skeleton (Table 2). Not all of the items listed

TABLE 2

Sex ratio of white infants, born at term to primiparae aged 25-29, who are housewives, whose husbands are professional men aged 30-34, according to nativity of the parents

Single live births occurring in hospitals in cities of 100,000 or more population, 1940-194-

YEAR	ALL NATIVITY GROUPS	NATIVE WHITE × NATIVE WHITE	NATIVE WHITE × ITALIAN *	ITALIAN × NATIVE WHITE	ITALIAN × ITALIAN	ETC.
.						
1940						
1941						
1942						
1943						
1944						
1945						
.						

* The nativity of parents (father × mother) is shown in the column headings. Italy has been selected to illustrate country of birth of foreign born white because according to the 1940 Census of Population, persons born in Italy comprise the largest percent of the foreign born white in the United States.

in the heading, stub, or box of the table would necessarily be included. The purpose of selecting items for inclusion would be to identify biologically comparable groups of infants.

Such a table would show variation in the sex ratio at birth from year to year during pre war, war, and post war years, for groups of infants that are biologically comparable as far as the information on birth certificate permits, i. e. infants that have the same characteristics, and for subgroups that classify these infants according to nativity of parents (Table 2). Similar tables could be made for other groups of infants that are also biologically comparable but differ from the preceding groups

with respect to one or more of the above characteristics. The number and kind of tables would depend on the interests of the investigator and on the facilities and funds at his disposal. These tables would furnish additional information concerning variation in the sex ratio during war and post war years and would also make possible comparison of the amount of variation in the sex ratios for groups of infants that are born the same year but differ biologically, and the amount of variation in the sex ratio during war and post war years for groups of infants that are biologically comparable to any one of the groups born the same year.[6]

The results of such a study as the one proposed may be negative. It may be unproductive because

1. It is based on live births only. It should include all products of conception; yet it cannot, because early intrauterine deaths are not generally reported, and, if they are reported, the sex of the infant is frequently unknown. These early intrauterine deaths[7] may be an important factor in the sex ratio at birth.[8]
2. The variation in the ratio is small, and, therefore, its association with the parental, infant, and socio-economic characteristics which are reported on the birth certificate may be difficult to demonstrate.

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[6] These additional tables could also be used to evaluate any one characteristic that may be associated with the sex ratio at birth, independent of other characteristics, which themselves may be associated with the sex ratio. For example, tables identical with the one illustrated with respect to all characteristics studied except age of mother might be used to study differences in the ratio associated with maternal age; *or* tables identical with the one illustrated except for maturity of the infant, might be used to study differences in the ratio associated with gestational age.

[7] According to Ciocco (page 56), intrauterine deaths are not the only or perhaps even primary factor in variation in the sex ratio. ". . . the annual changes in the live birth sex ratio do not reflect annual changes in either the stillbirth rate which measures the extent of intra-uterine mortality or in the sex ratio of the stillborn, presumably a measure of the vitality of the male foetus." See Antonio Ciocco: Variations in the sex ratio at birth in the United States, HUMAN BIOLOGY, 10, No. 1, 36-64, 1938.

[8] Studies in the literature indicate that (1) the mortality of the male fetus is relatively very high in the early months of pregnancy, and (2) about half of the abortions occur during the first three months.

It is hoped, however, that such a study will furnish evidence concerning the sex ratio at birth,[9] which , in turn may lead to experimental studies on animals, and have clinical and sociological implications.

SUMMARY OF A PARTIAL SURVEY OF THE LITERATURE ON VARIATIONS IN THE SEX RATIO AT BIRTH DURING WAR AND POST WAR YEARS [10]

The literature on variations in the sex ratio at birth as a consequence of war is unsatifactory. Most of the studies in the literature are based on an examination of routine vital statistics or on theoretical considerations only. They have controlled only a few factors at a time in studying the variation in the ratio.

One can find supporting evidence for or against many of the explanations of an increase in the sex ratio at birth during and immediately following a war. In fact, there is even disagreement in the literature concerning the existence of the phenomenon.

Many factors associated with an increase in the sex ratio at birth as a consequence of war have been discussed in the literature. They may be classified as follows:

1. Factors connected with the war

   A. Length of the war

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[9] There is another problem that has a direct bearing on the sex ratio at birth, namely the completeness of reporting of female as compared to male births. There is indirect evidence to indicate that in some areas the reporting of female births may be less complete than the reporting of male births. In these areas, the sex ratio for reported births is probably somewhat larger than the sex ratio for total births.

Note also that the tendency for certain population groups to report stillbirths as live births, increases the sex ratio for these population groups as the sex ratio for stillbirths is larger than the sex ratio for live births.

There is still another problem which has a bearing on the sex ratio: Research now being conducted by Dr. B. J. Tepping of the Bureau of the Census indicates that census enumerators record a female as a male more often than they record a male as a female, and there is a possibility that this phenomenon carries over to the reporting of births.

As a result of these and other biases, it may well be that the sex ratio at birth appears to be higher than it actually is.

[10] For a selected bibliography, see Edward P. Hutchinson: Research on the Social Effects of War as Reflected by Vital Phenomena (Social Science Research Council, 1942), pp. 41-42.

B. Participation in the war
   i. Amount
   ii. Type
   iii. Outcome

2. Maternal factors
   A. Residence
   B. Nutrition
   C. Age
   D. Parity or condition in respect to having borne children
   E. Number of previous pregnancy losses
   F. Interval between this pregnancy and the one immediately preceding
   G. Type of delivery

3. Paternal factors
   A. Occupation
   B. Age

4. Infant factors
   A. Condition at birth
      i. Live born
      ii. Stillborn (including abortions)
   B. Gestational age or maturity

5. Genetic factors
   A. Sex ratio at conception
   B. Cross breeding [11]
   C. Functional changes in the zygotes or fertilized eggs [12]
   D. Lenz' theory. Lenz attributes the post war rise in the sex ratio to two phenomena: (1) the large proportion of first births; (2) the tendency for runs of female births to occur in families, particularly in countries in which the birth rate is declining.[13] Lenz attributes the higher sex ratio of first births to the greater ability of sperm containing the Y-chromosome than sperm containing the X-chromosome to reach and penetrate the egg, especially under conditions associated with first births.[14]

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[11] The sex ratio for hybrids is apparently larger than the ratio for "pure" strains.

[12] This hypothesis can be confirmed only by a study of two generations, as a functional change in the zygotes is reflected in the sex ratio of the second generation. See Julian S. Huxley: A statistical method of testing the biological causes underlying the excess of male births during the war, *The Eugenics Review*, 13, No. 4, 549-550, 1922.

[13] No evidence has been found in the literature to confirm this hypothesis.

[14] If the egg is entered by a sperm carrying the Y-chromosome, the fertilized egg will develop into a male.

For a detailed discussion of Lenz' theory, particularly the problem of genetic pathology of the male, see Fritz Lenz, *Eine Erklärung der Schwankens der Knabenziffer*, Archiv für Rassen und Gesellschaftsbiologie, 11, No. 5, 629-632, 1916.

E. Sexual demands on the male with resulting increase in the number of young sperm, which, it is assumed, are more likely to contain the Y-chromosome than the X-chromosome

F. Late impregnation of the egg. Late impregnation is assumed to favor sperm carrying the Y-chromosome

6. Migration, which results in crossbreeding [11]

7. Social and economic upheavals

8. Other
   A. Religious affiliation
   B. Teleological.

NOTES

A NOTE ON THE VARIANCE OF SEX RATIOS

IN HUMAN BIOLOGY, 14 (1): 85-94, 1941 *(On the Variance of Human Live Birth Sex Ratios)* H. Strandskov analyzes the remarkable natural phenomenon that male births always exceed female births, usually without any great secular variation. The variation in the male sex proportion was studied through the use of the powerful statistical tool termed "analysis of variance" for the United States Birth Registration Area by years for 1923-37.

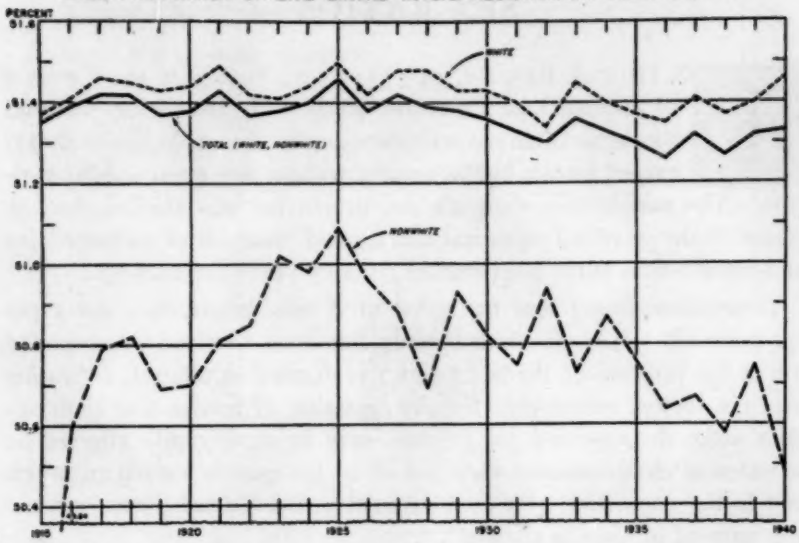
Strandskov found that the value of F was larger than the 5 per cent point for the U. S. Birth Registration Area over a 15-year period so that the variance of the sex ratios was deemed significant, indicating that "the factors responsible for the deviation of human live birth sex ratios from the expected 50:50 ratio may be significantly affected by the external environmental variation or by the genetic variations which exist in the population of a country such as the United States, when a long interval of time is allowed".

The studies made by Strandskov follow quite closely the earlier ones made by Ciocco (2). The importance of the Strandskov study is that it applies the powerful tool, analysis of variance, to this problem. Both studies reached the same conclusion as to variation of the sex ratio by States and by months, but Ciocco found that there was not a significant difference for the total United States for a 20-year interval, whereas Strandskov found the reverse.

Consideration of the sex ratio for the Birth Registration Area from 1923-37 should have been carried out separately by race as did Ciocco. While the genetic composition of the United States as a whole did not change strikingly over the interval considered, this was not the case tor the Birth Registration Area which had an under-representation of Southern states prior to its including all states in 1932. Thus, for

example, in 1923 only 8.3 per cent of the births were non-white, whereas in 1932 and 1937 the corresponding figures were 12.1 per cent and 12.5 per cent respectively. Since the sex ratio for non-whites is so much lower than for whites (roughly, 50.8 per cent as compared with 51.4 per cent) the inclusion of an increasing proportion of non-white births would automatically tend to lower the total sex ratio. This is illustrated by Fig. 1 from which it may be seen that for total births the

MALE PROPORTION OF LIVE BIRTHS IN U.S. REGISTRATION AREA, 1915-40



sex ratio had a rather steady decline from 1925 until 1932 with a somewhat level trend thereafter. On the other hand, the trend for white births is much more level with only a slight indication of a downward trend since 1925. The non-white sex ratios are considerably lower than the white ones and show far greater annual fluctuations partly because of the known unreliability of non-white reporting of vital statistics and partly because of the smaller numbers involved. The especially low value for 1915 is explained by the fact that only 12,000 non-white births were reported in the area of that year.

The previous discussion has been based on graphical conclusions, but in Table 1 the problem is studied by using the analysis of variance method. For the 1923-1937 period there is found to be a significant variation for total persons (as did Strandskov), but for white persons

TABLE 1

Summary of analysis of variance data for sex proportion of live births annually in U. S. Birth Registration Area, 1923-37

CATEGORY	$\sigma_e^2 \times 10^{10}$	$\sigma_T^2 \times 10^{10}$	F	5 PER CENT POINT [a]	SIGNIFICANCE
		Using no weights for years [b]			
White	2,052	1,351	1.52	1.69	No
Non-white	19,873	11,024	1.80	1.69	Yes
Total persons [c]	2,884	1,203	2.40	1.69	Yes
		Using weights for years [b]			
White	2,056	1,351	1.52	1.69	No
Non-white	17,519	11,024	1.59	1.69	No
Total Persons	2,839	1,203	2.36	1.69	Yes

[a] From Table 10.3, *Statistical Methods* by G. W. Snedecor, with degrees of freedom of 14 for σ_e and ∞ for σ_T, with the 5 per cent point depending on these two figures and on whether σ_e or σ_T is greater.

[b] In the upper half of the table the observed σ^2 is computed by adding the squares of the differences between the male proportion for each year and the average value for the entire period and then dividing by the number of degrees of freedom. In the lower half of the table the squared differences are weighted by the ratio of the births in the given year to the average annual births over the entire period prior to adding.

[c] The figures in this row agree exactly with those obtained by Strandskov in his Table 4.

the value of F lies below the 5 per cent point so that the fluctuations shown on the figure may be merely random. However, for non-whites there is found to be a significant difference.

This brings up the point that a modification seems necessary in the procedure adapted for utilizing the analysis of variance method. Strandskov used each of the sex ratios for the different years as having the same weight regardless of the number of births upon which it was based. This procedure would be valid if all the categories were of approximately the same size. However, when this is not the case, it does not seem logical to give the same weight to a sex ratio based on

a small number of births, where violent random fluctuations can be expected, as to a sex ratio based on a much larger number of births. This is particularly so for non-white births where, because of the growth of the registration area, there was a relatively small number in the early years of the period considered. Therefore, there has been adopted the empirical method of weighting each of the squared differences between the sex ratio of that category and the average for the grand total by the ratio of the births in the given year to the average annual births over the entire period. As shown by the lower half of Table 1, for the period 1923-37 the value of F for whites and total persons is little affected by such weighting, but for non-white births F falls within the 5 per cent point and indicates that the variations could well be random rather than significant.

In summary, this analysis has indicated that there has been no indication of a significant variation in the male sex proportion of live births in the United States over the past few decades insofar as white persons are concerned. However, in the case of non-white persons, it appears as though there may have been some significant variations since there is present a clearly downward trend from 1932 on. Whether or not this trend is more apparent than real, because of the somewhat dubious reliability of non-white vital statistics data, should be a subject of further analysis.

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Robert J. Myers
U. S. Army

RECENT LITERATURE

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